Delaware Department of Natural Resources and Environmental Control

APPENDICES

MURDERKILL RIVER WATERSHED TMDL MODEL DEVELOPMENT AND CALIBRATION

Prepared by:

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KCDW – 178287

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APPENDIX 1

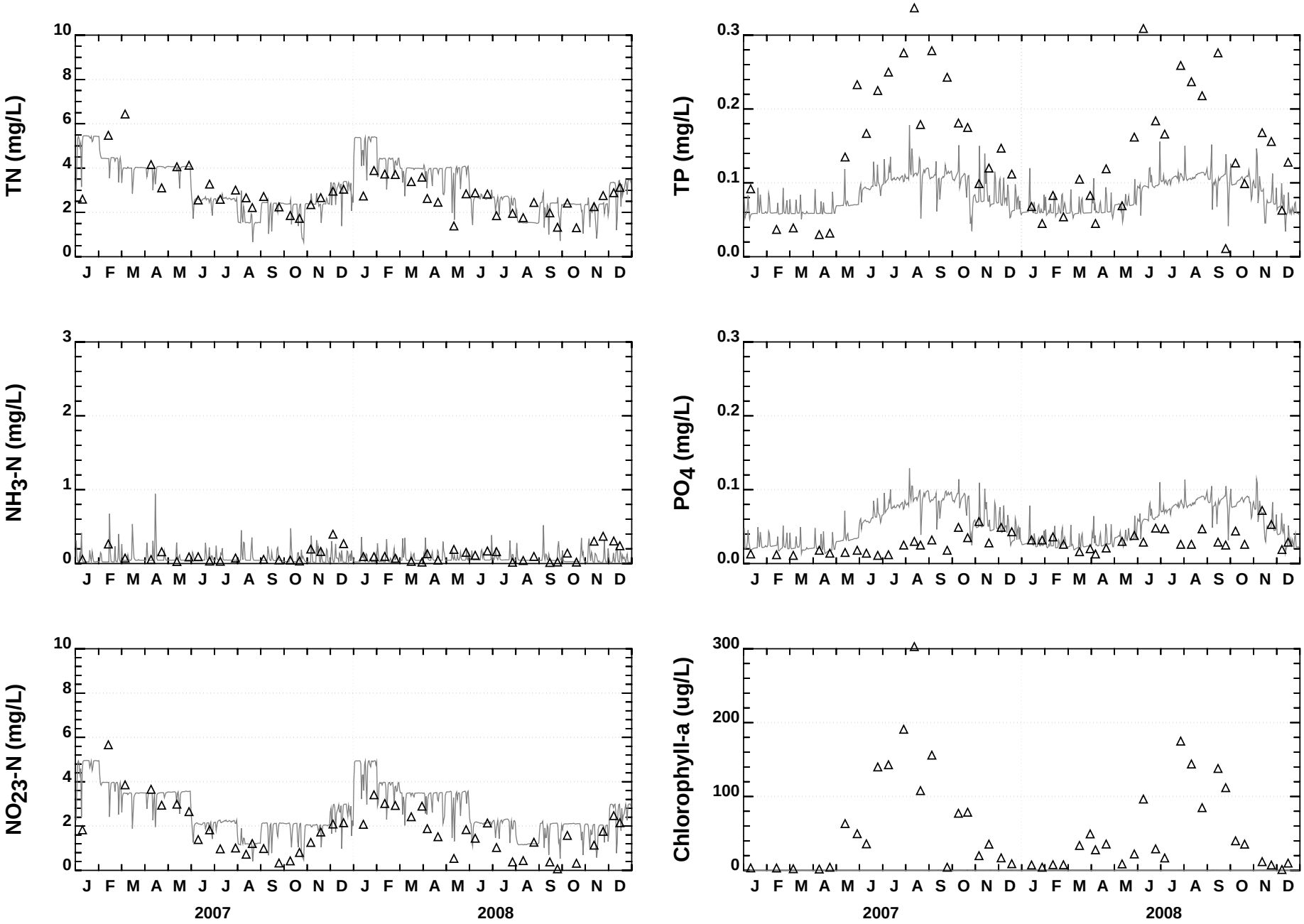
HSPF MODEL SUBWATERSHED LAND USE

Murderkill River Watershed HSPF Subwatershed Land Use (Areas in acres)

	Agricultural	CAFO	Forest	Open Water	Pasture or Rangeland	Residential			Streets or Parking	Transitional	Urban			Wetlands	Total		
Reach	PERLND	PERLND	PERLND	PERLND	PERLND	IMPLND	PERLND	Total	IMPLND	PERLND	IMPLND	PERLND	Total	PERLND	IMPLND	PERLND	Total
RCHRES 2	2628	0	701	13	7	635	635	1270	24	116	17	17	34	457	676	4574	5250
RCHRES 3	260	0	40	8	5	27	27	54	0	0	0	0	0	25	27	365	392
RCHRES 4	1882	16	216	7	26	552	552	1104	27	44	51	51	102	782	630	3576	4206
RCHRES 5	833	0	130	40	0	122	122	244	0	2	13	13	26	54	135	1194	1329
RCHRES 6	201	0	77	13	0	27	27	54	0	0	0	0	0	24	27	342	369
RCHRES 7	1829	21	259	3	27	203	203	406	23	21	30	30	60	138	256	2531	2787
RCHRES 8	521	0	71	21	13	121	121	242	0	0	0	0	0	28	121	775	896
RCHRES 8	521	0	71	21	13	121	121	242	0	0	0	0	0	28	121	775	896
RCHRES 9	118	0	89	12	0	26	26	52	0	0	0	0	0	11	26	256	282
RCHRES 10	264	0	196	19	0	7	7	14	0	0	0	0	0	41	7	527	534
RCHRES 11	952	0	264	42	0	31	31	62	16	0	11	11	22	211	58	1511	1569
RCHRES 12	1623	21	341	4	39	254	254	508	13	32	26	26	52	595	293	2935	3228
RCHRES 13	3267	12	786	19	22	143	143	286	22	12	6	6	12	995	171	5262	5433
RCHRES 14	1120	19	219	2	27	26	26	52	14	0	29	29	58	159	69	1601	1670
RCHRES 15	225	2	214	74	3	89	89	178	0	0	0	0	0	51	89	658	747
RCHRES 16	1283	19	345	22	2	58	58	116	14	0	22	22	44	120	94	1871	1965
RCHRES 17	501	0	44	38	0	31	31	62	0	0	0	0	0	9	31	623	654
RCHRES 18	852	0	113	94	0	53	53	106	2	0	0	0	0	105	55	1217	1272
RCHRES 19	1442	25	422	13	14	150	150	300	0	39	1	1	2	98	151	2204	2355
RCHRES 20	1175	0	274	4	6	196	196	392	4	0	68	68	136	166	268	1889	2157
RCHRES 21	783	0	292	19	16	337	337	674	32	14	145	145	290	543	514	2149	2663
RCHRES 22	1	0	2	0	0	0	0	0	0	0	1	1	2	3	1	7	8
RCHRES 23	1607	5	389	35	0	229	229	458	15	116	56	56	112	224	300	2661	2961
RCHRES 24	625	11	141	39	74	67	67	134	0	157	0	0	0	114	67	1228	1295
RCHRES 25	211	0	33	43	0	22	22	44	0	0	0	0	0	6	22	315	337
RCHRES 26	1265	9	267	72	182	104	104	208	0	0	0	0	0	158	104	2057	2161
RCHRES 27	3405	10	434	69	16	152	152	304	10	14	23	23	46	562	185	4685	4870
RCHRES 28	2871	13	504	116	25	95	95	190	57	33	38	38	76	1289	190	4984	5174
TOTAL	**31744**	**183**	**6863**	**841**	**504**			**7514**	**273**	**600**			**1074**	**6968**			**56564**

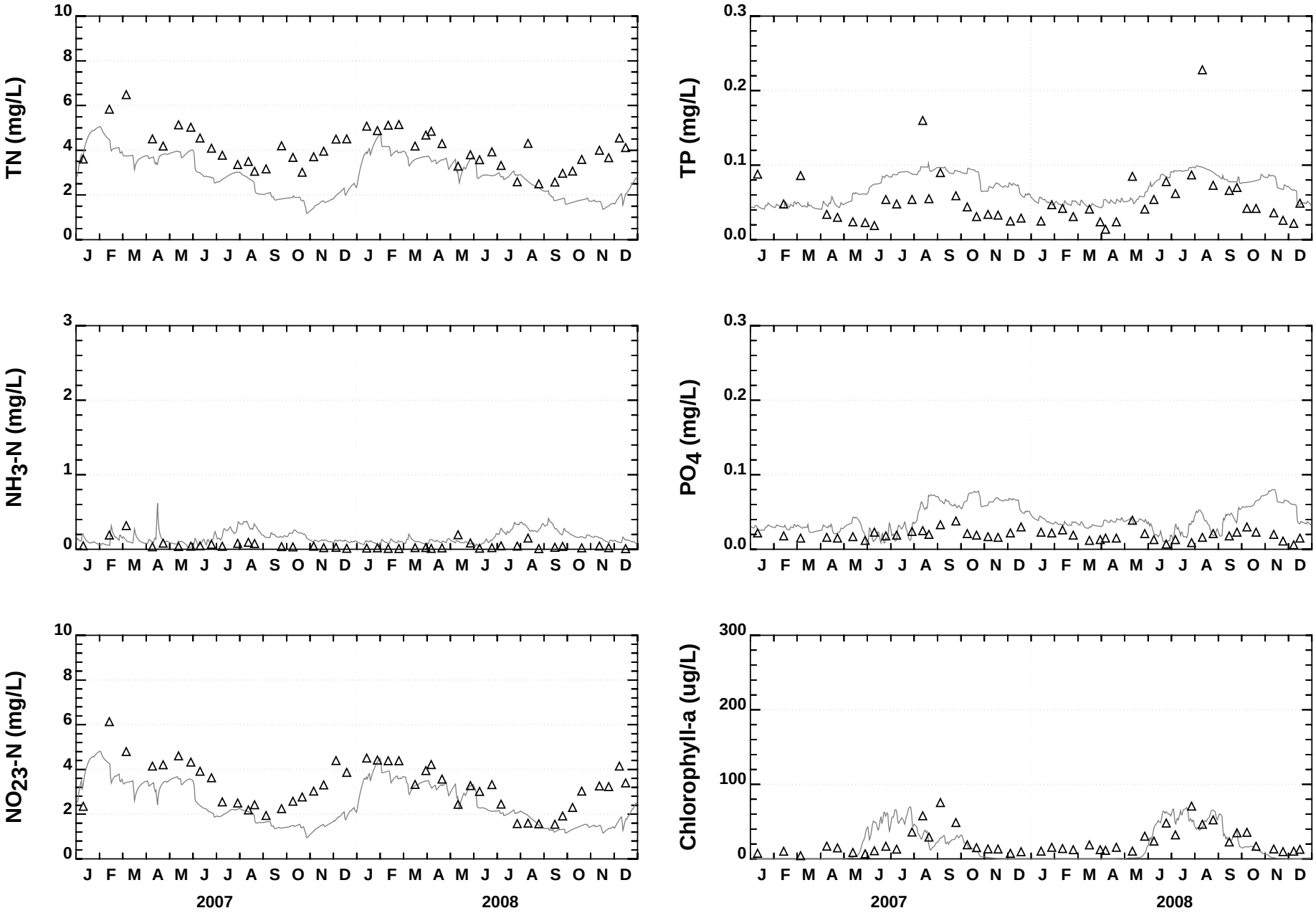
APPENDIX 2

HSPF MODEL
CALIBRATION/VALIDATION
FIGURES



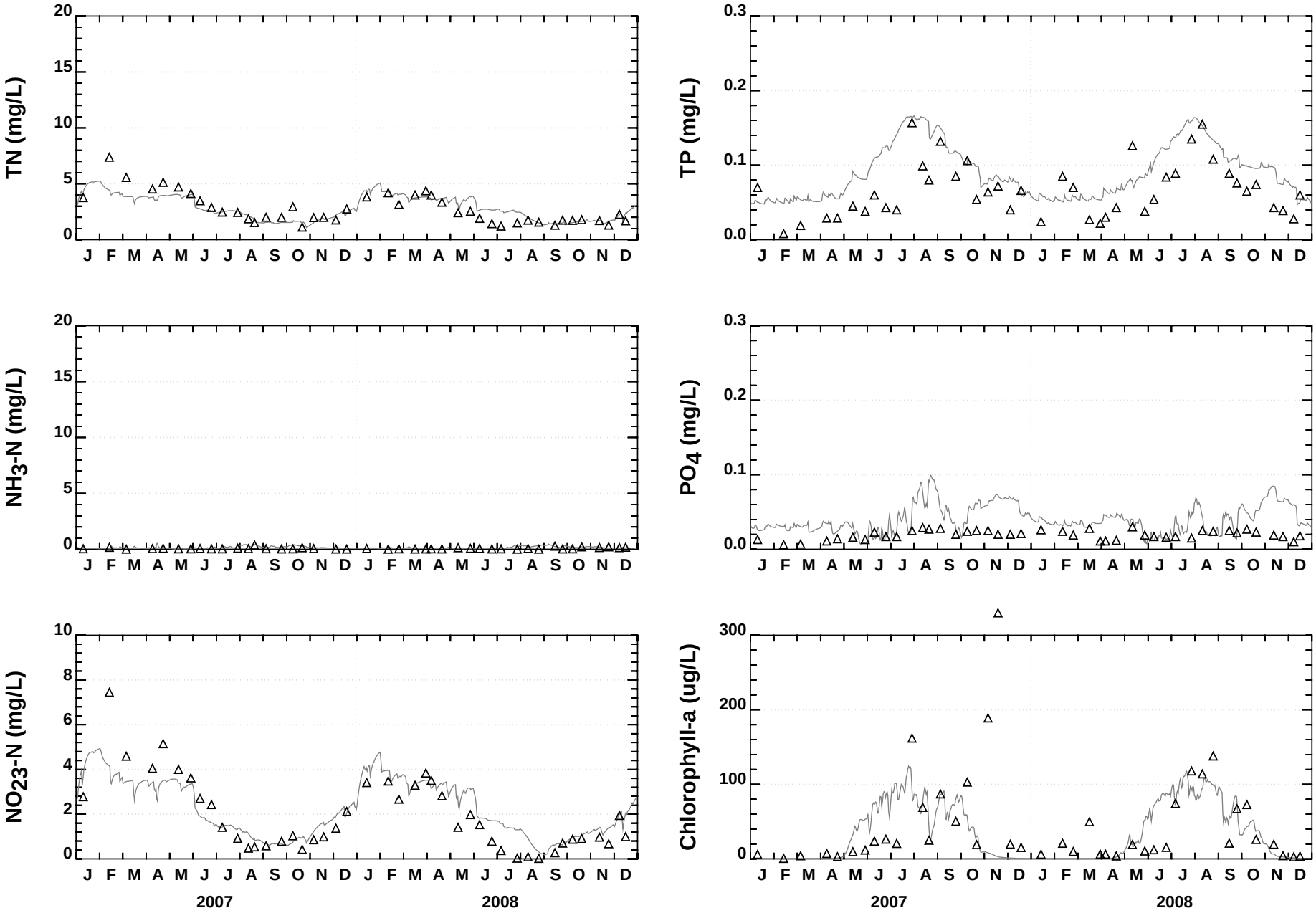
Run046 - RUN046 with Septics (25% Failure)

Water Quality Data at Station 206561, Double Run at Barratts Chapel Rd. (Rd. 371)



Run046 - RUN046 with Septics (25% Failure)

Water Quality Data at Station 206461, McGinnis Pond at McGinnis Pond Rd. (Rd. 378)



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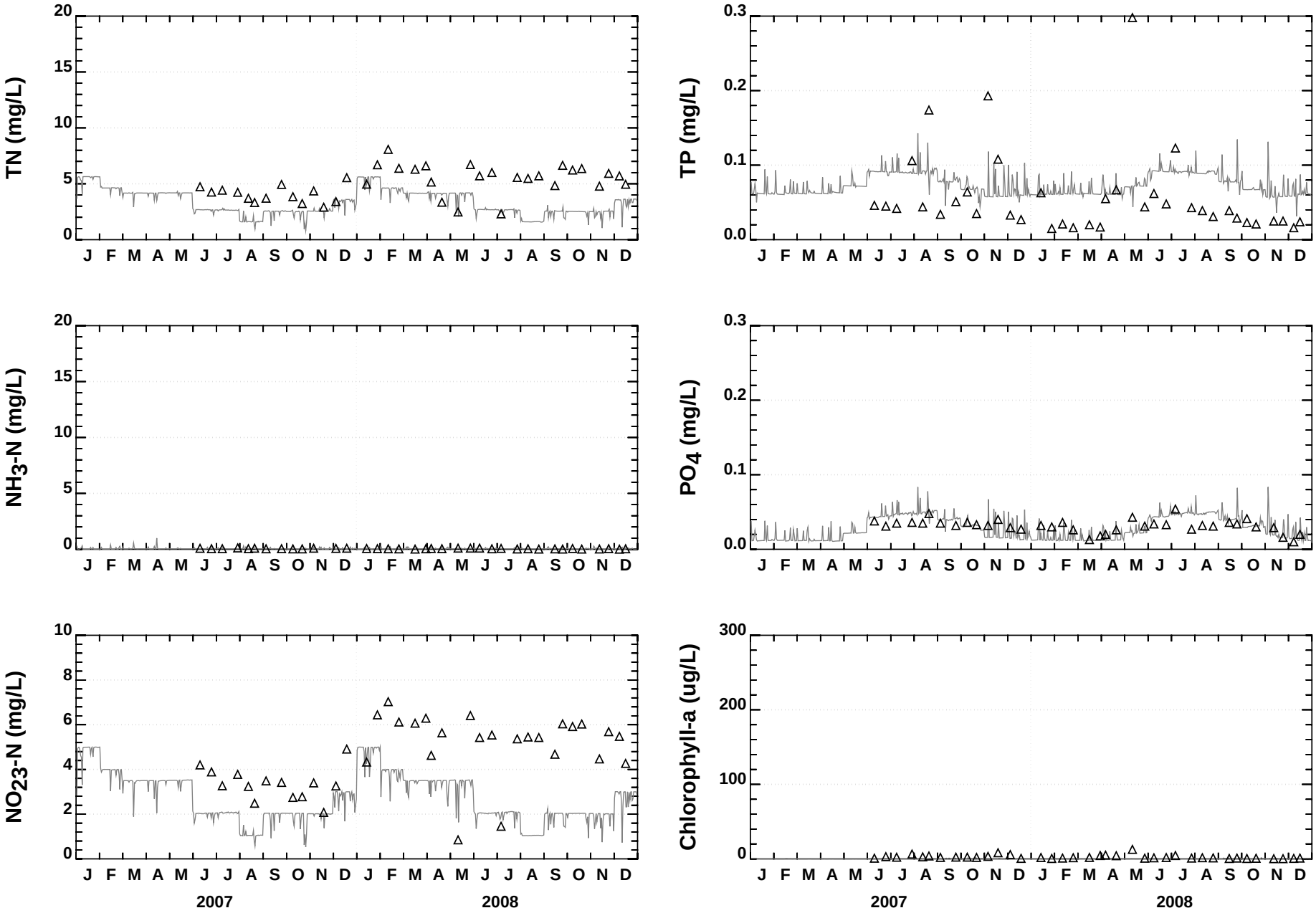

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Water Quality Data at Station 206641, Spring Creek, Pratt Branch at Canterbury Rd.

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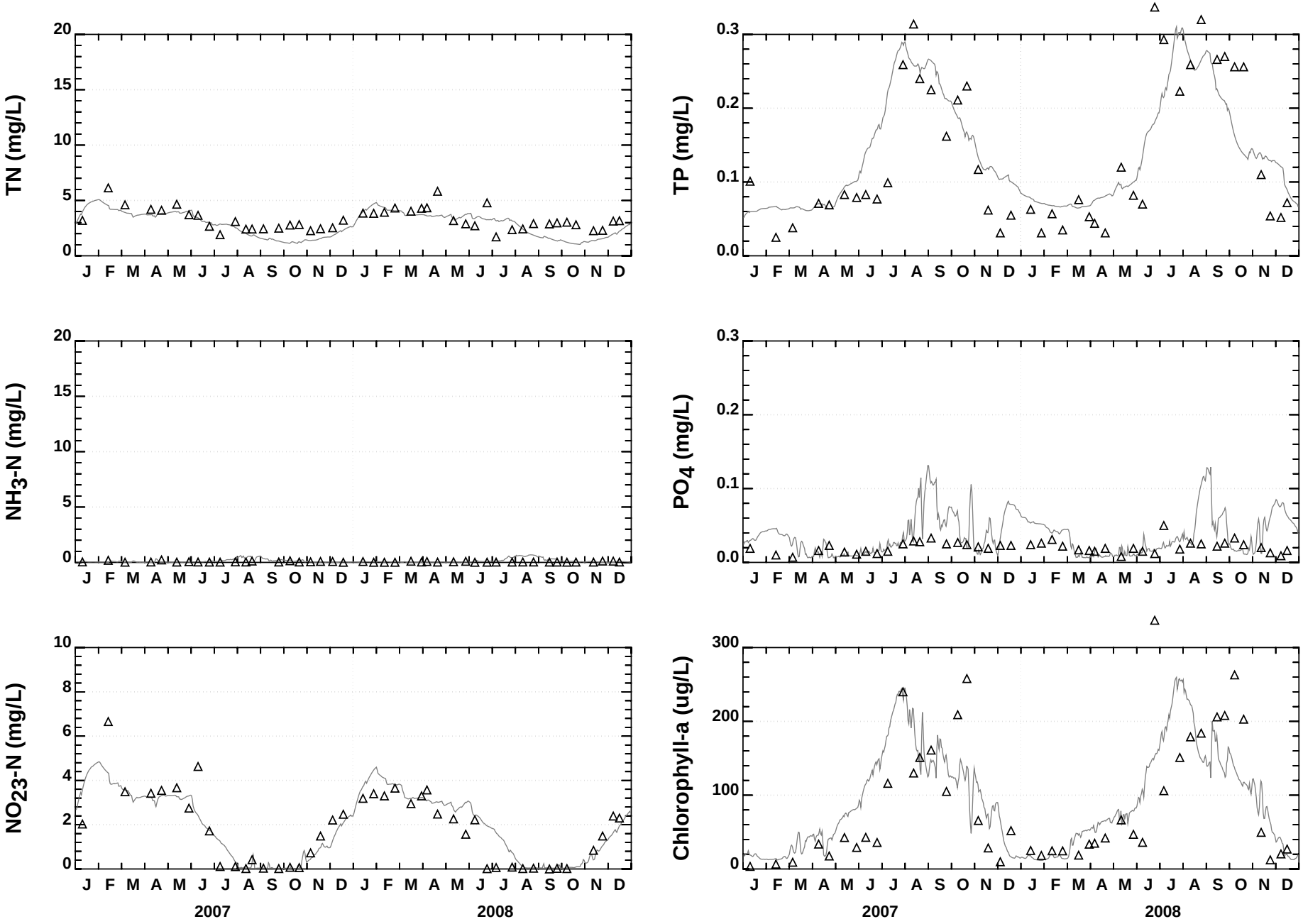

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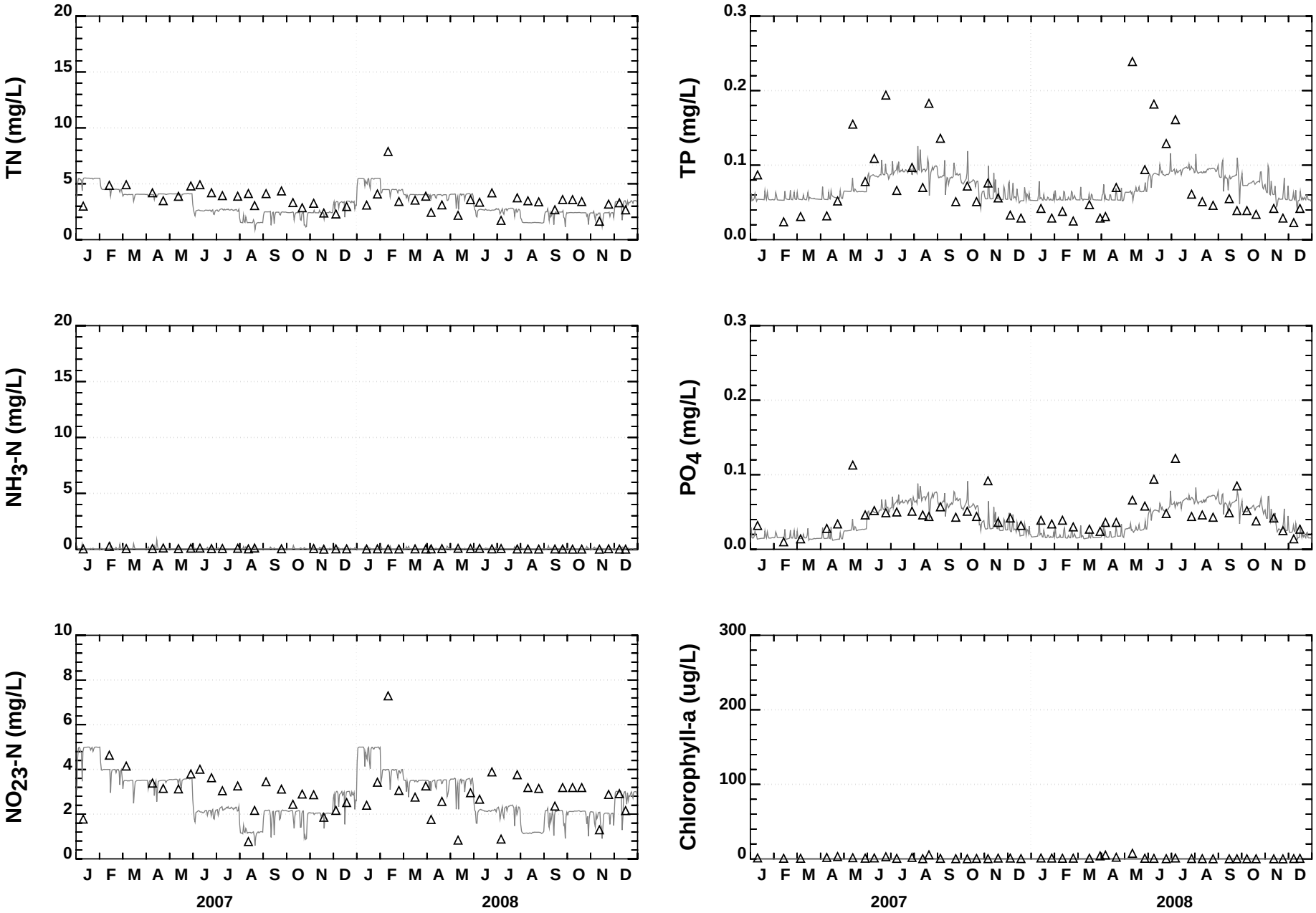

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Water Quality Data at Station 206011, Murderkill River at Confluence of Black Swamp Creek

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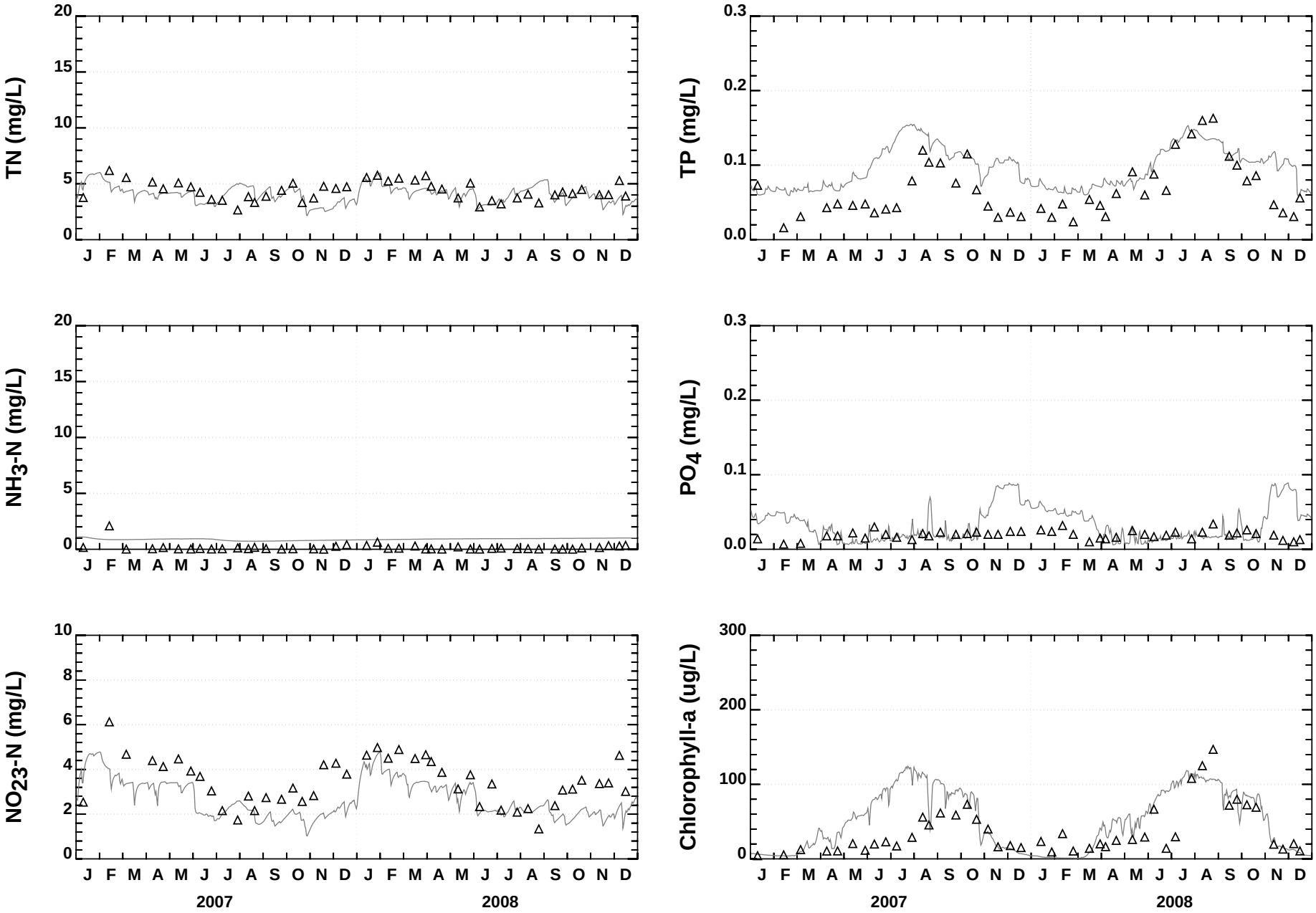

Run046 - RUN046 with Septics (25% Failure)

Water Quality Data at Station 206361, McColley Pond at Canterbury Rd. (Rt. 15) near Spillway

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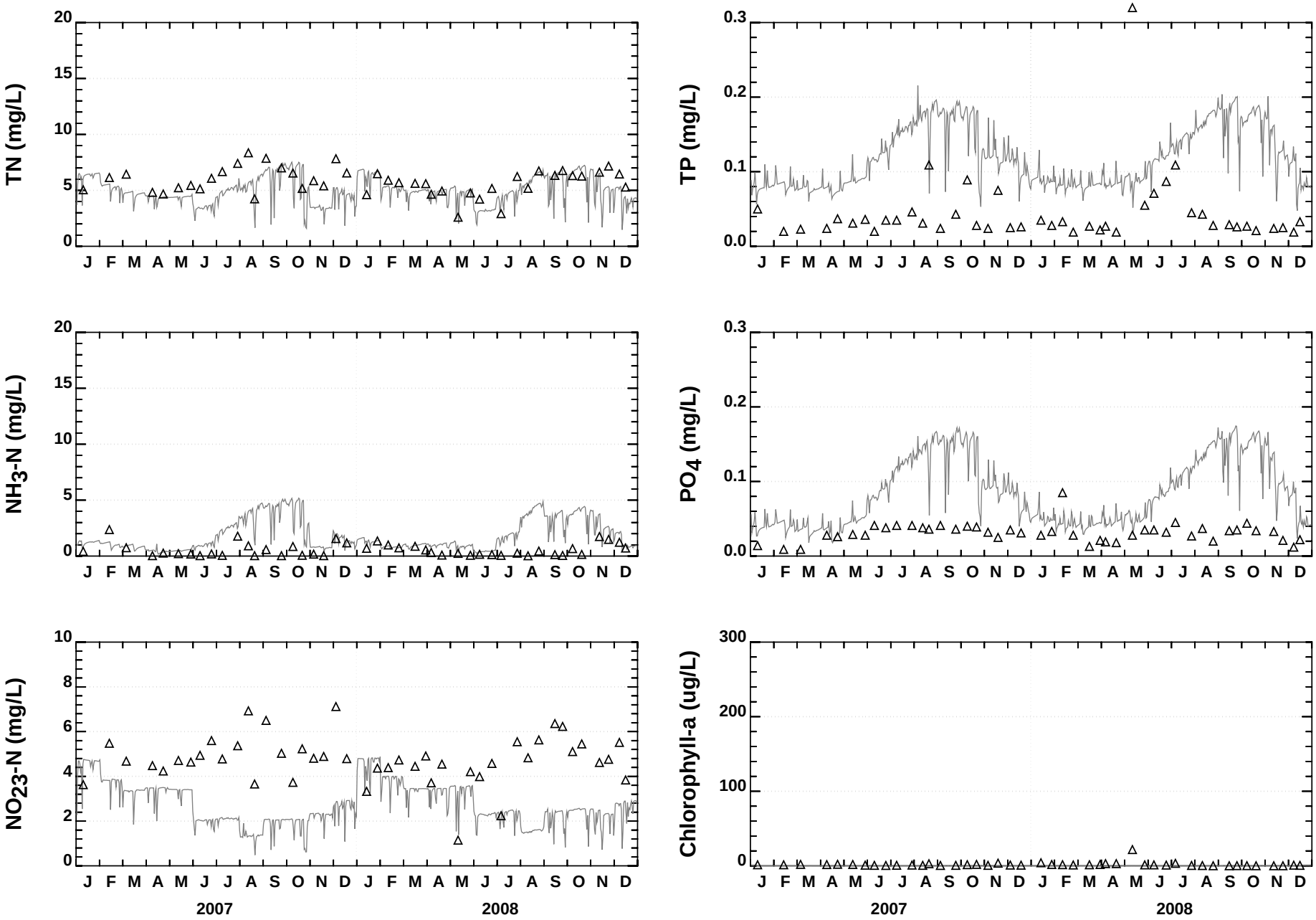

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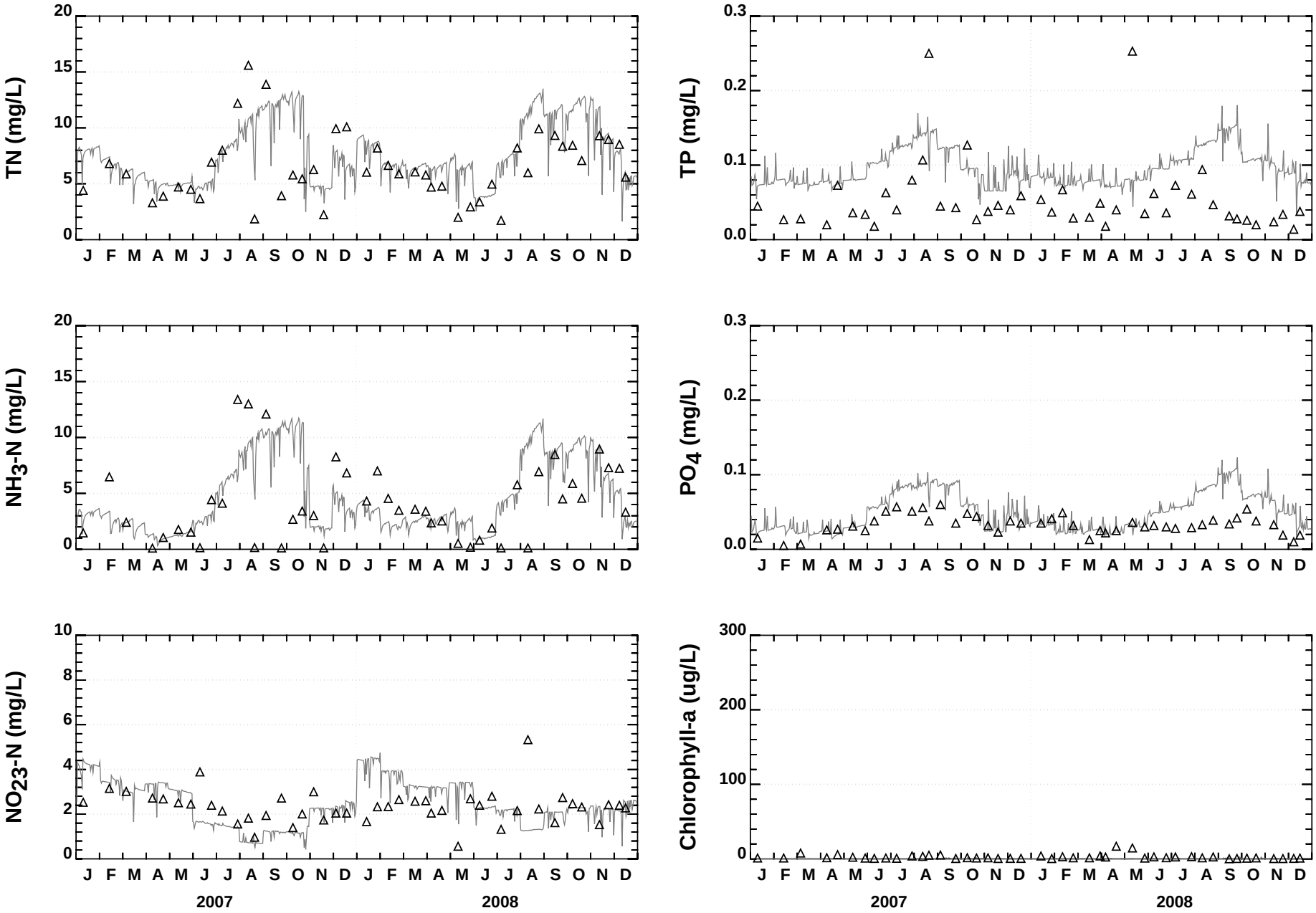

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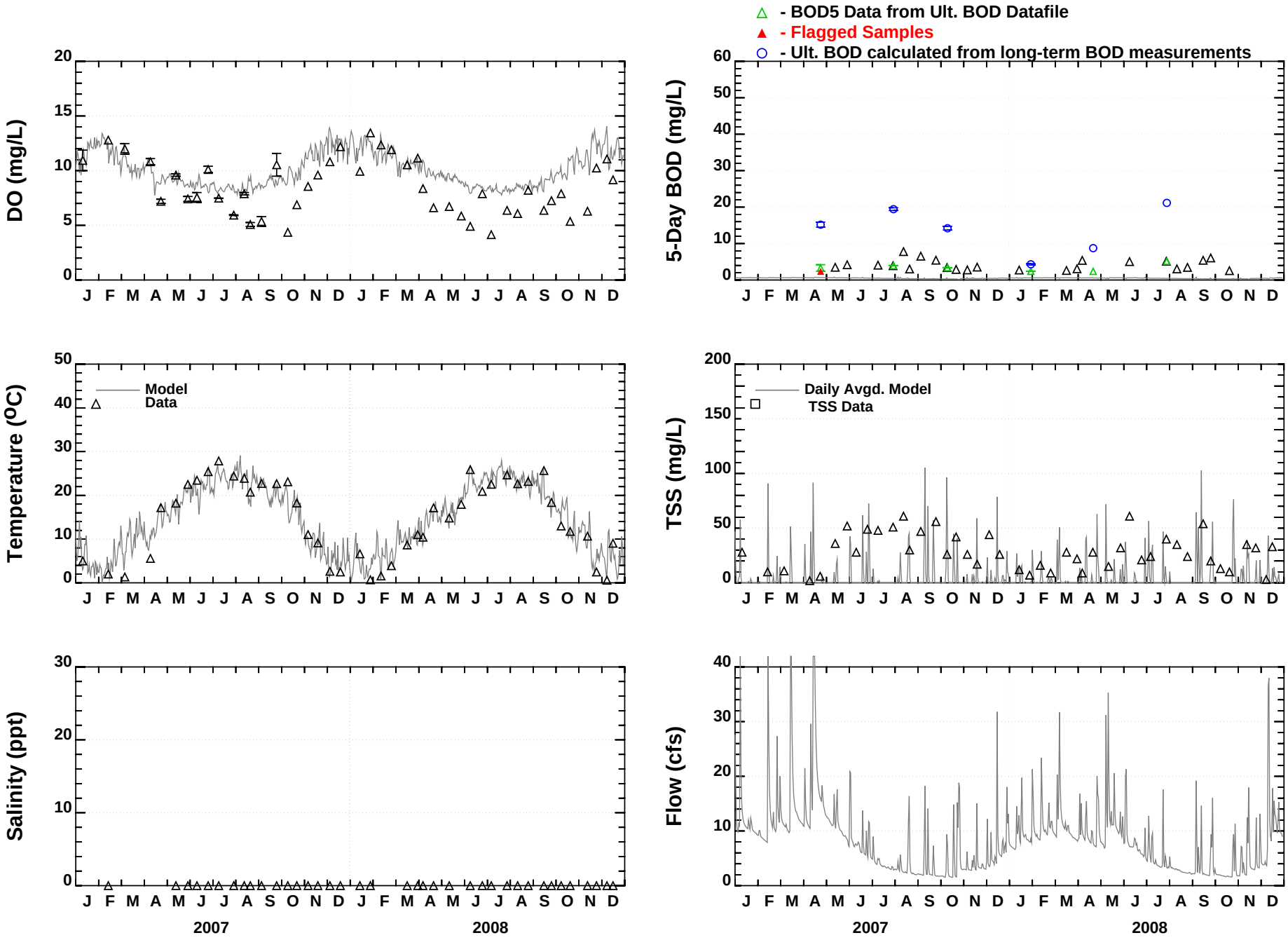

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Water Quality Data at Station 206561, Double Run at Barratts Chapel Rd. (Rd. 371)

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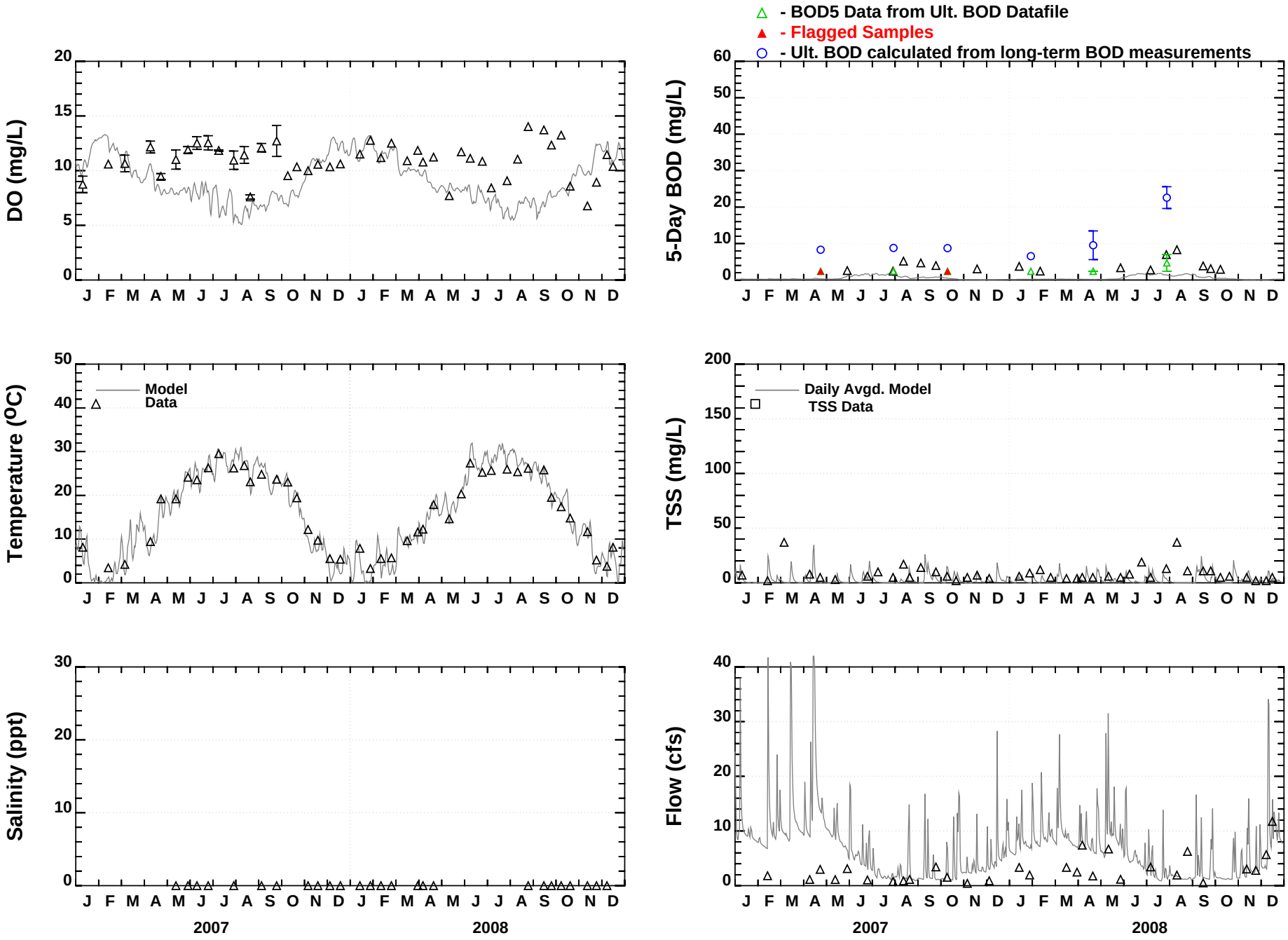

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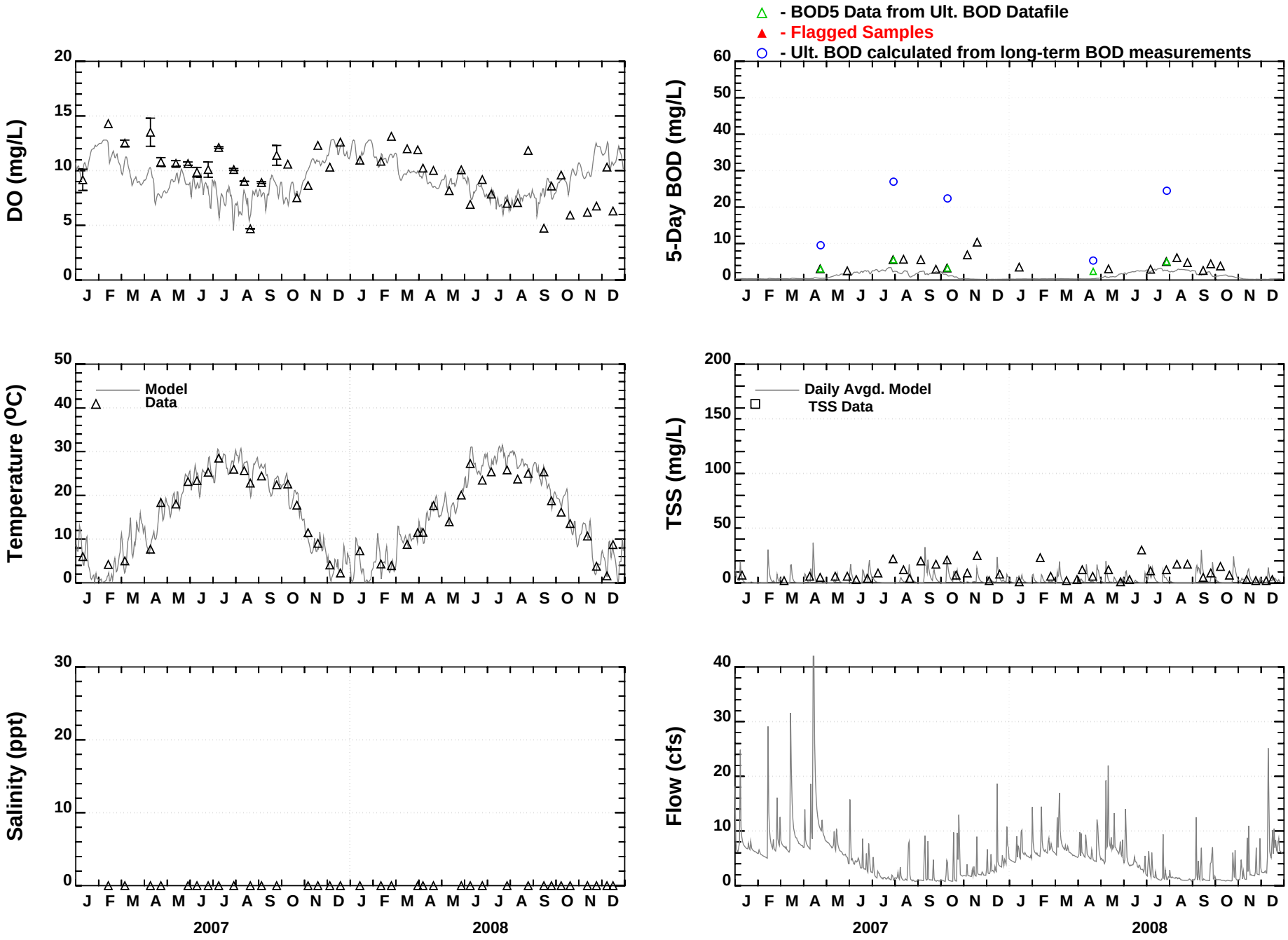

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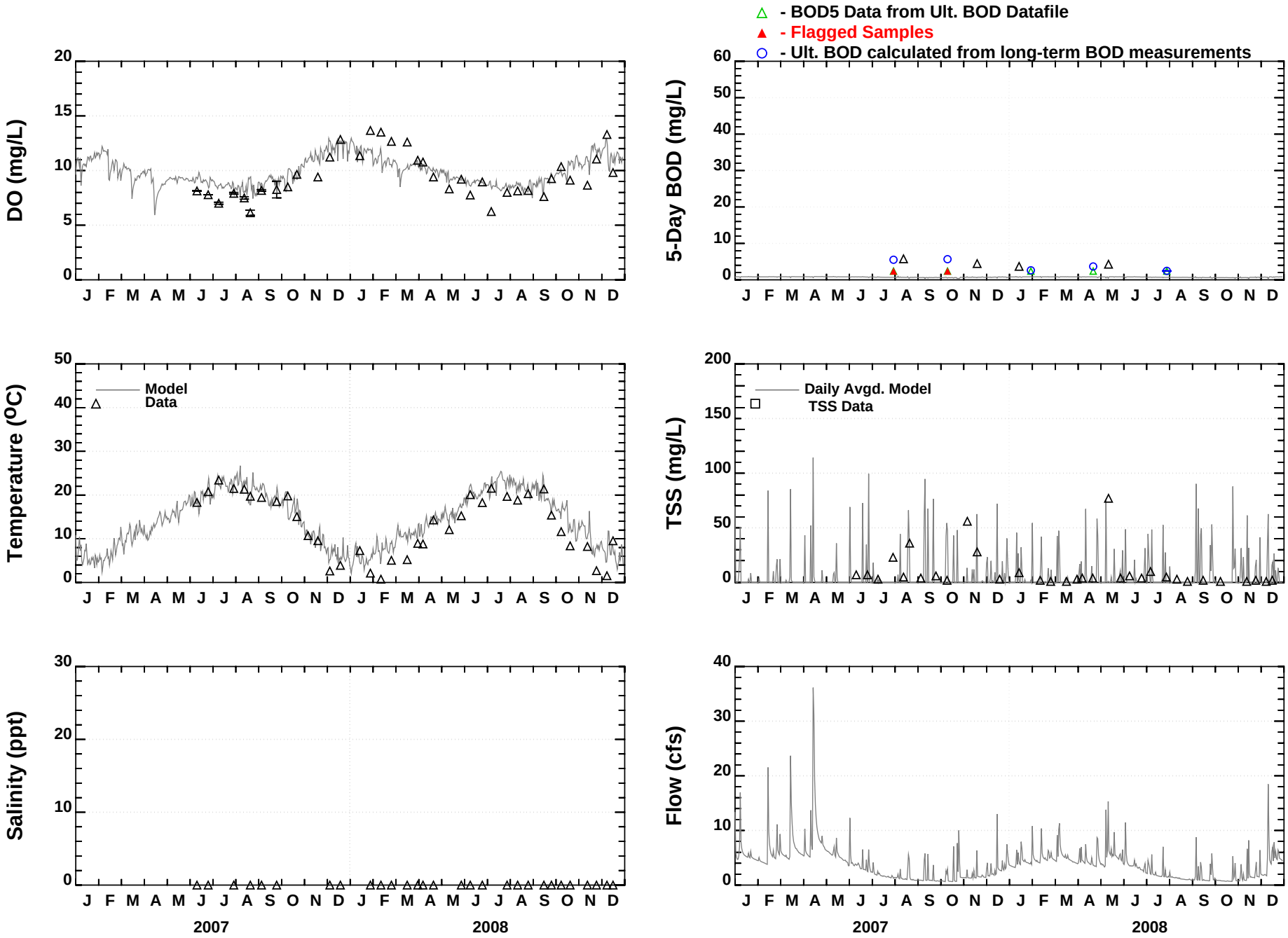

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Water Quality Data at Station 206641, Spring Creek, Pratt Branch at Canterbury Rd.

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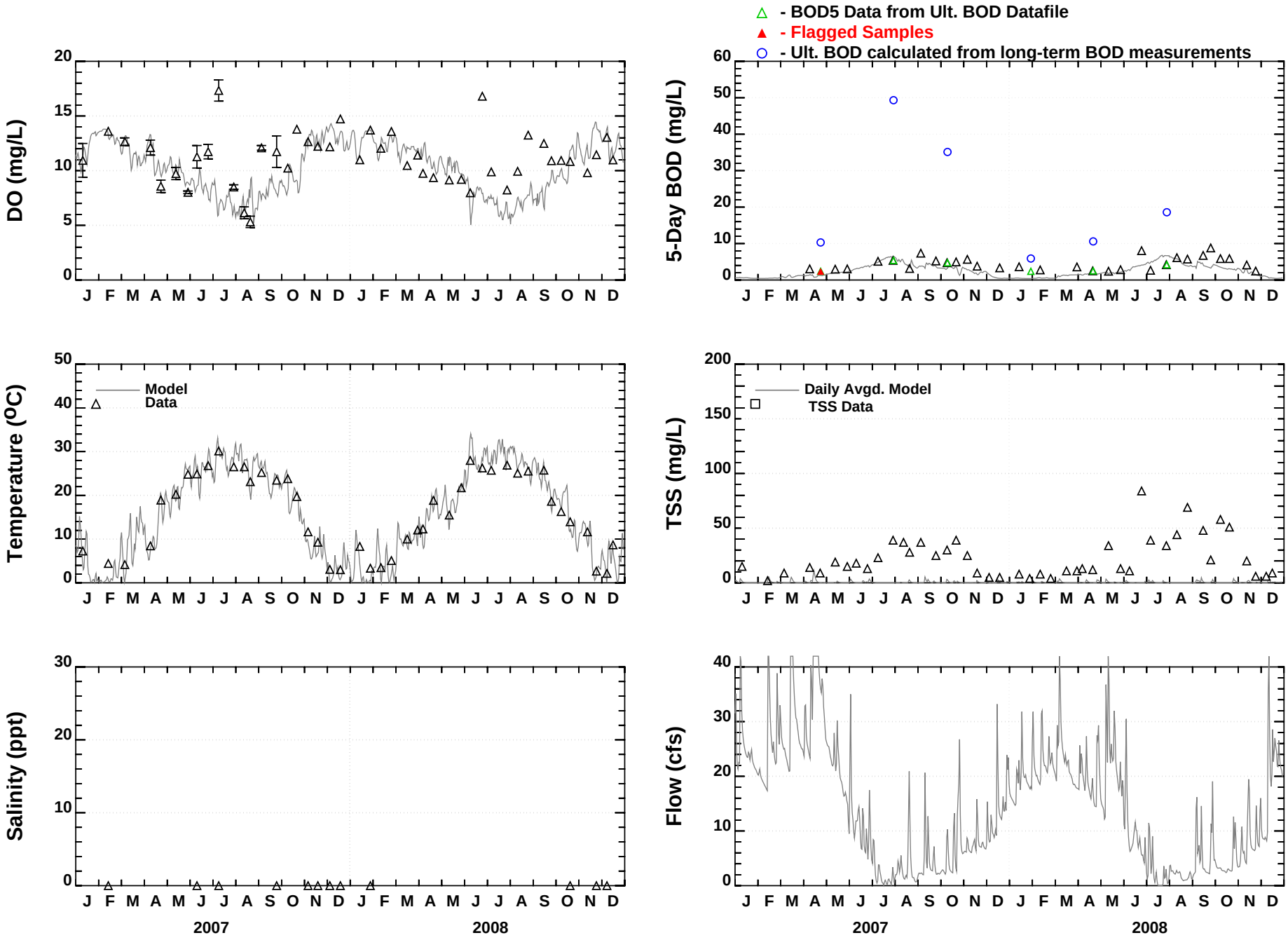

RUN046 with Septics (25% Failure)

Water Quality Data at Station 206451, Coursey Pond at Canterbury Rd. (Rt. 15) at Rd. 388 Bridge

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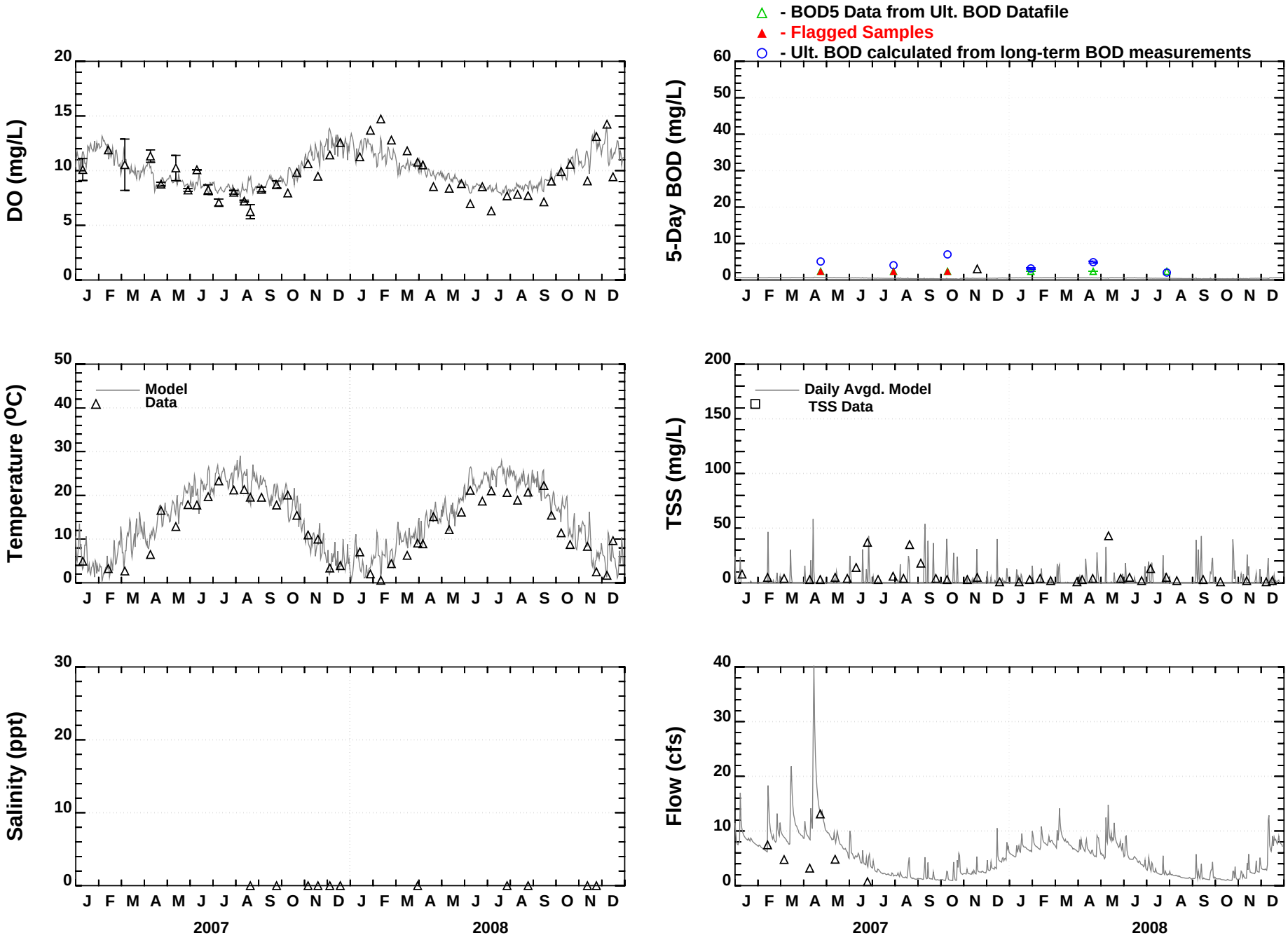

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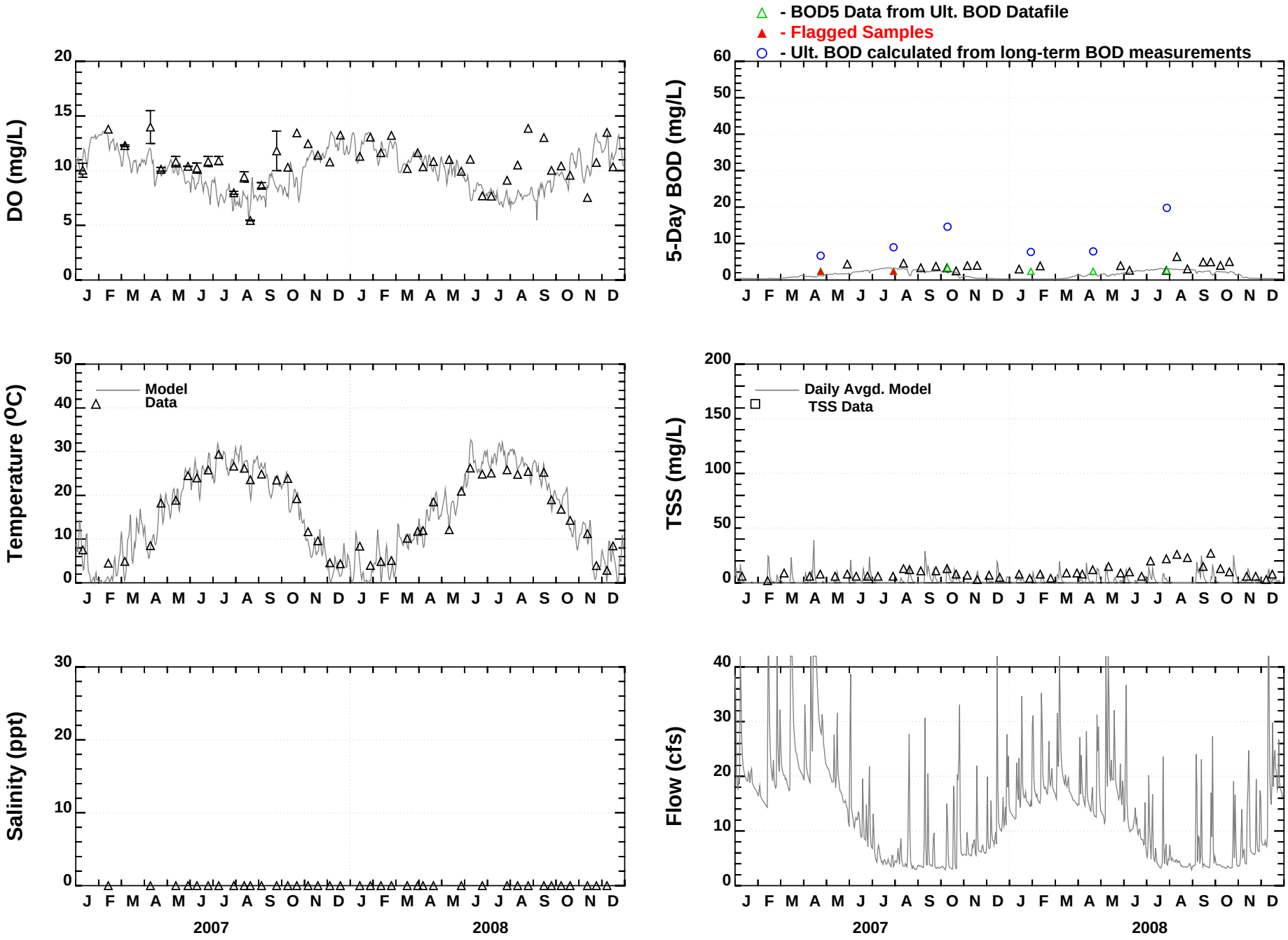

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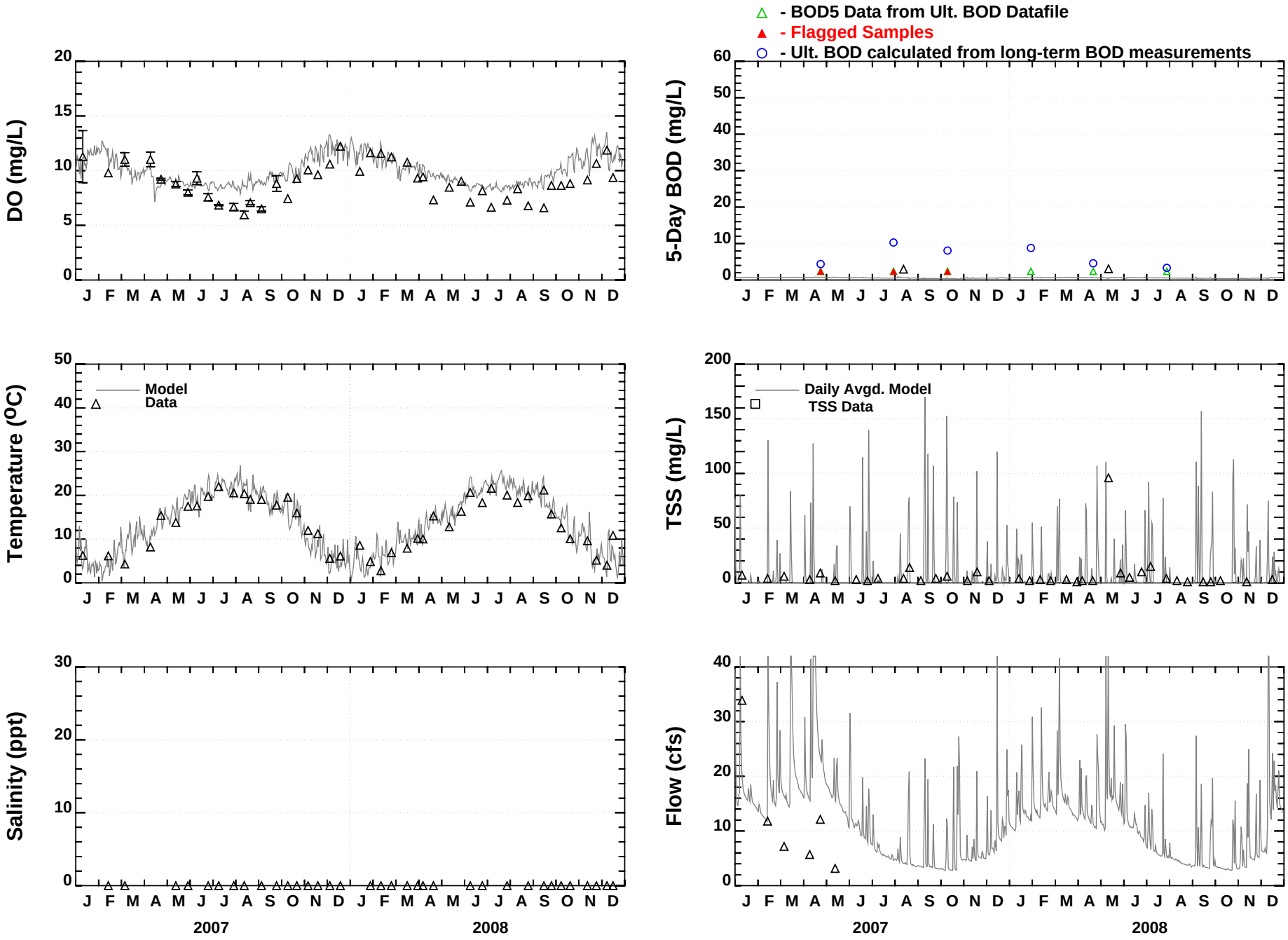

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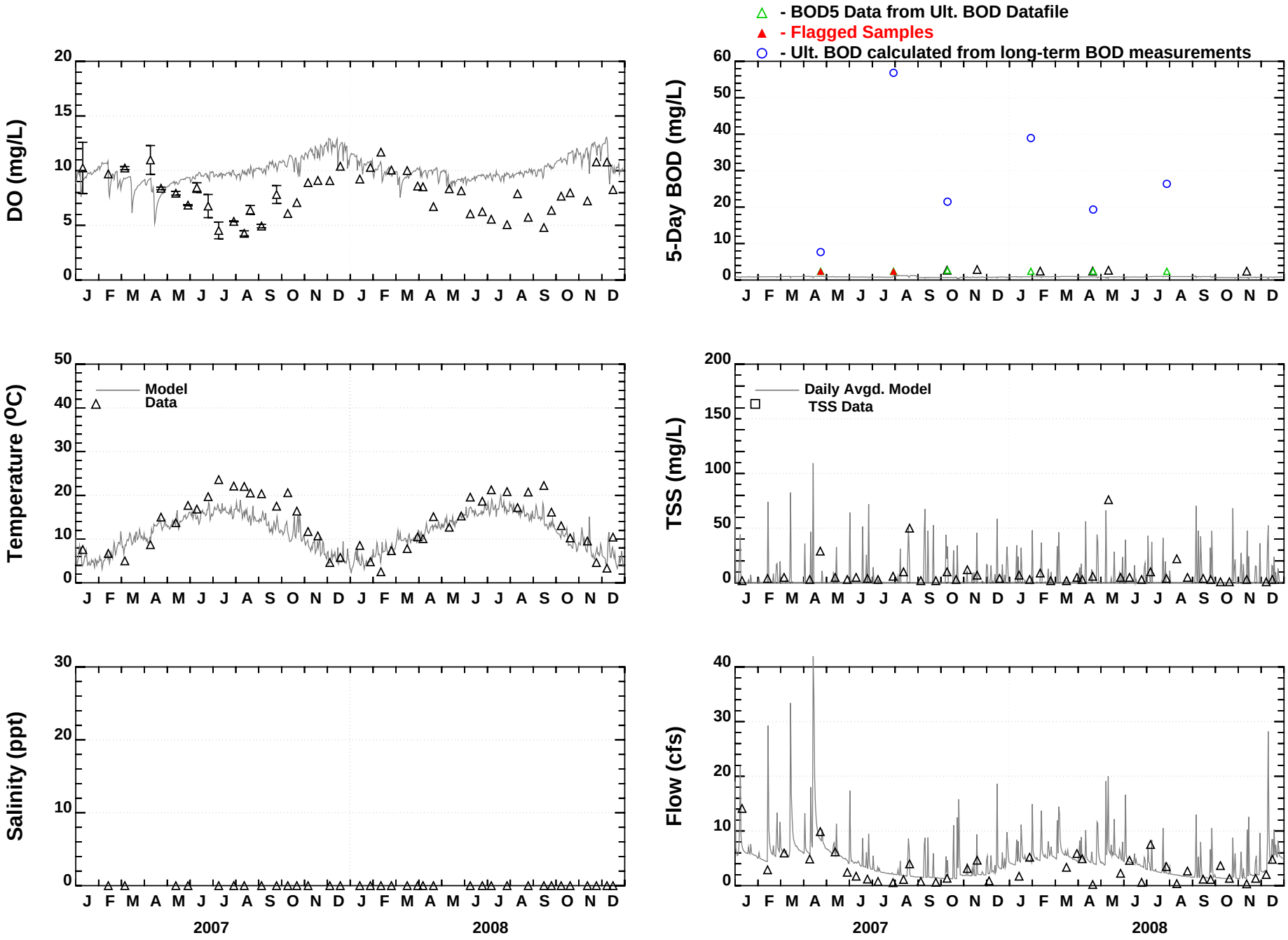

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APPENDIX 3

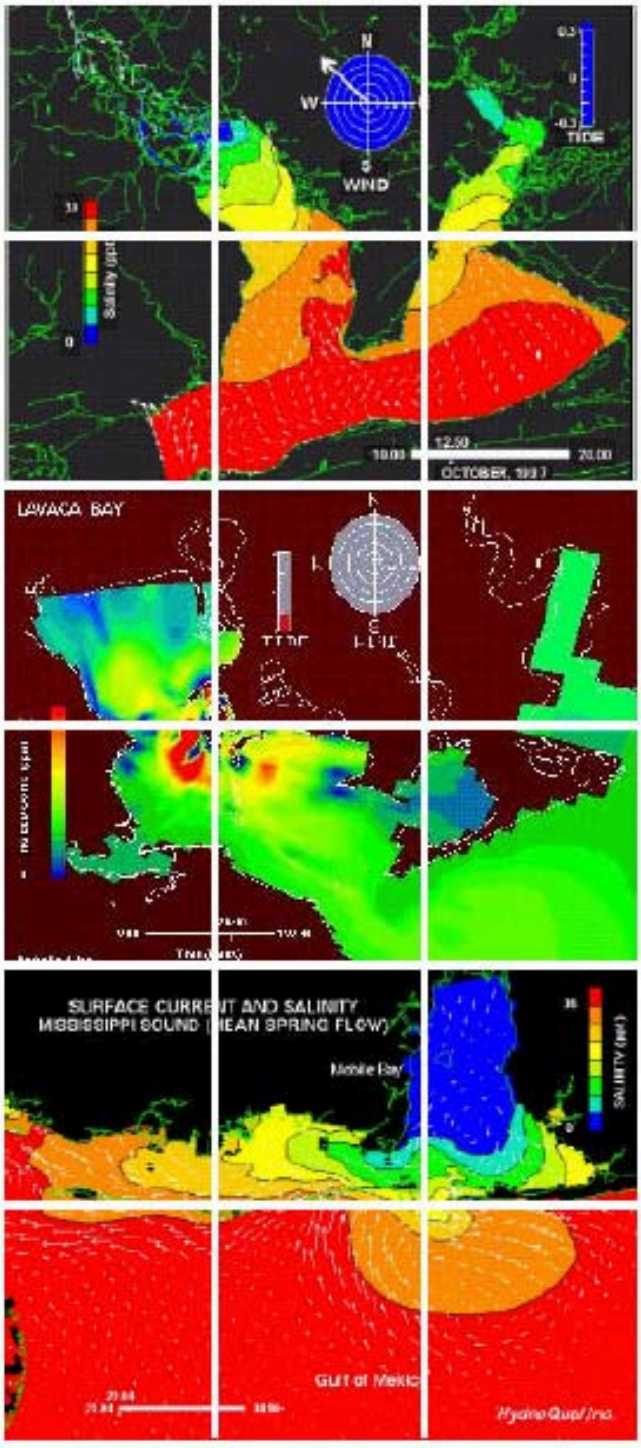
ECOMSED DOCUMENTATION

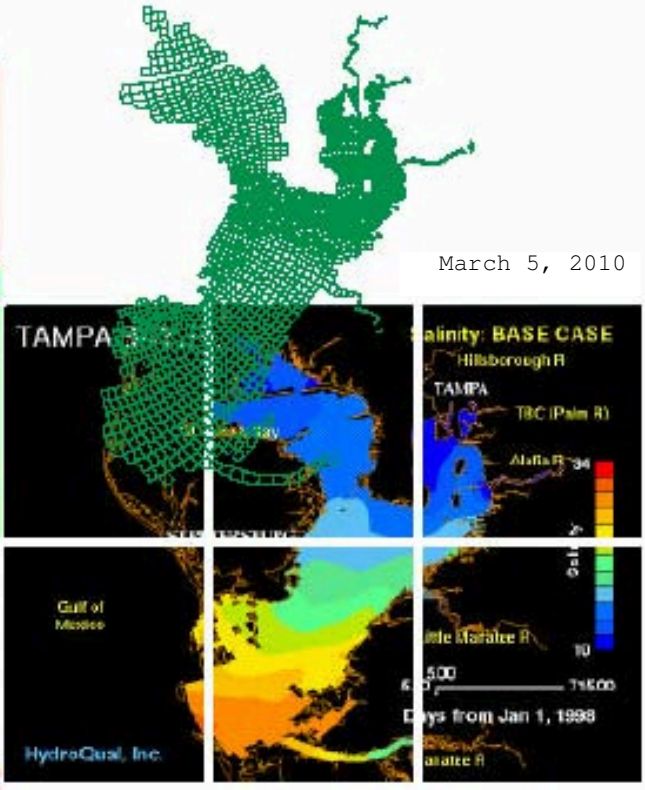
A Primer for

ECOMSED

Version 1.4-LPR

Users Manual





March 5, 2010

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HydroQual

Environmental Engineers & Scientists

1.0 Introduction 1

2.0 ECOMSED Model Features 2
2.1 Internal/External Hydrodynamics 2
2.2 Sediment Transport 2
2.3 Sediment-bound Tracer Transport 4
2.4 Dissolved Tracer Transport/Pathogen Fate Model 4
2.5 Particle Tracking 4
2.6 Wind Waves 5

3.0 Hydrodynamic Module 6
3.1 Introduction 6
3.2 The Governing Equations 7
3.2.1 Dynamic and Thermodynamic Equations 7
3.2.2 Turbulence Closure 9
3.2.3 Boundary Conditions 11
3.2.4 Open Lateral Boundary Condition 12
3.2.4.1 Temperature and Salinity 12
3.2.4.2 Water Level Boundary Condition 13
3.2.4.2.1 Clamped Boundary Condition 13
3.2.4.2.2 Inverted Reid and Bodine Boundary Condition 13
3.2.4.2.3 Optimized Clamped Boundary Condition . 14
3.3 Vertical Coordinate Representation 14
3.4 Mode Splitting Technique 19
3.5 Orthogonal Curvilinear Coordinate System Transformation 21
3.6 Surface Heat Flux 26

4.0 Tracer/Pathogen Fate Module 28

5.0 Particle Tracking Module 30

6.0 Sediment Transport Module 33
6.1 Introduction 33
6.2 SEDZL Modeling Framework 33
6.2.1 Governing Equation 34
6.2.2 Bottom Shear Stress Computations 35
6.2.3 Resuspension of Cohesive Sediments 36
6.2.4 Deposition of Cohesive Sediments 36
6.2.5 Cohesive Sediment Bed Model 42
6.2.6 Resuspension of Noncohesive Sediments 42
6.2.7 Deposition of Noncohesive Sediments 48
6.2.8 Noncohesive Sediment Bed Armoring 48
6.3 SEDZLJ Modeling Framework 49
6.3.1 Erosion 49
6.3.2 Non-Cohesive Bedload vs. Suspended Load Fractionation 50
6.3.3 Bed Consolidation 52

7.0 Wave Module 55
7.1 Introduction 55
7.2 Wave Induced Bottom Shear Stress 59
8.0 Solution Technologies and Overall Characteristics of ECOMSED 61
8.1 Finite Difference Formulation 61
8.1.1 Finite Differencing 61
8.1.2 Subgrid Scale Parameterizaton 61
8.1.3 Stability Constraints 63
8.2 Advection Algorithms 64
8.3 Thin Dams 65
8.4 Semi-Prognostic Density Computations 65
8.5 Empirical Vertical Turbulent Mixing 65
8.6 netCDF Output Format 66
8.7 Flooding and Drying 66

9.0 Structure of Computer Code 70
9.1 Fortran Symbols 70
9.2 Program Structure 72

10.0 Model Input Data Structure 83
10.1 Model Geometry Input Data 83
10.2 Initial Condition 87
10.3 Model Simulation Input Data 88

11.0 Model Output Data Structure 193

References 202

List of Figures

Figure Page

2-1. Modeling Framework (ECOMSED). 3
3-1. The Sigma Coordinate System 16
3-2. A simplified illustration of the interaction of the External Mode and the Internal Mode. 22
6-1 Resuspension potential as a function of bed shear stress for twelve different aquatic systems (based on shaker studies). 37
6-2 Settling speed function for cohesive sediments settling in saltwater compared to mean values of Burban et. al. (1990) data. 39
6-3 Comparison of Krone (1962) and Partheniades (1992) formulations for the probability of deposition of cohesive sediments 41
6-4 Schematic of the sediment bed model 43
6-5 Settling velocity as a function of particle diameter for noncohesive sediments (based on Cheng, 1997 formulation). 45
7-1. Curvilinear coordinate system 57
8-1. The locations of the variables on the finite difference grid 62
8-2. Schematic illustration of the ECOMSED Grid 68
8-3. Flow chart of wetting/drying scheme 69
9-1. ECOMSED flowchart 73

List of Tables

Table Page

3-1. Heatflux Formulations in ECOMSED Model 27
9-1. Fortran Symbols 70
9-2. Components of the Computer Programs 78
9-3. Mass Storage Files 81
10-1A. model_grid data structure 83
10-1B. model_grid data format 84
10-2A. Data structure of init_tands 87
10-2B. init_tands data format 87
10-3A. Data structure of run_data 88
10-3B. Data format of run_data 91
10-4A. synop_wind INPUT FILE SUMMARY OF DATA GROUPS 120
10-4B. synop_hflx INPUT FILE SUMMARY OF DATA GROUPS 121
10-5. corner_loc INPUT FILE 122
10-6. Summary of User Created Input Files for Transport Calculations 123
10-7. water_trace.inp INPUT FILE 124
10-8. coh_sed.inp INPUT FILE for SEDZL 132
10-9. noncoh_sed.inp INPUT FILE 141
10-10. coh_trace.inp INPUT FILE 147
10-11. noncoh_trace.inp INPUT FILE 153
10-12. partrack.inp INPUT FILE 159
10-13. bed_mask INPUT FILE 161
10-14. p0_init INPUT FILE 162
10-15. a0_init INPUT FILE 163
10-16. exp_init INPUT FILE 164
10-17. bed_d50 INPUT FILE 165
10-18. bed_frac.mud INPUT FILE 166
10-19. bed_frac.sand INPUT FILE 167
10-20. bed_bulkden INPUT FILE 168
10-21. bed_chemic INPUT FILE 169
10-22. hqi_geom INPUT FILE (UNFORMATTED) 170
10-23. hqi_tran INPUT FILE (UNFORMATTED) 171
10-24. wave_input INPUT FILE (UNFORMATTED) 172
10-25. horcon2d.inp INPUT FILE 173
10-26. Bfric2d.inp INPUT FILE 174
10-27. umol2d.inp INPUT FILE 176
10-28. Z0b2d.inp INPUT FILE 177
10-29 Init_tracer INPUT FILE 129
10-30 bed.sdf INPUT FILE 130
10-31 erate.sdf INPUT FILE 186
10-32 core_field.sdf INPUT FILE 189
10-33 coh_sed.inp INPUT FILE for SEDZLJ 190
11-1. Summary of Model Generated Output Files 193
11-2. gcmplt OUTPUT FILE (UNFORMATTED) 194

11-3. gcmtsr OUTPUT FILE (UNFORMATTED) 297
11-4. part_location OUTPUT FILE (FORMATTED) 199
11-5. gcm_tran OUTPUT FILE (UNFORMATTED) 200
11-6. gcm_geom OUTPUT FILE (UNFORMATTED) 201

PREFACE

The development of ECOMSED has its origins in the mid 1980's with the creation of the Princeton Ocean Model (Blumberg and Mellor, 1987) and its version for shallow water environments – rivers, bays, estuaries and the coastal ocean and reservoirs and lakes- named ECOM (Blumberg, 1996). In the mid 1990s, concepts for cohesive sediment resuspension, settling and consolidation (Lick, et al., 1984) were incorporated within the ECOM modeling framework. During the last several years, ECOMSED was enhanced to include generalized open boundary conditions, tracers, better bottom shear stresses through a submodel for bottom boundary layer physics, surface wave models, noncohesive sediment transport, and dissolved and sediment-bound tracer capabilities. The code has been reconfigured to be easily ported to almost any computer system, from PCs to workstations to super mainframes. Model performance has been evaluated by appealing to a large series of simple test cases designed to isolate specific processes and by application of the model to many real-world situations. There have been over 350 journal articles written that are based on the use of the various ECOMSED submodels. While there is a real confidence that ECOMSED is "bug free", it remains the user's responsibility to check and recheck their own results via their own test cases and their own comparisons with data.

The ECOMSED system has proven over the years to be quite robust and reliable. A user's guide on the other hand has been elusive. The material presented herein is directed towards the goal of a detailed, well documented manual that hopefully will allow enable an educated user to address real world environmental problems using sophisticated technology with the labor of learning all the details of the model's composition.

Today's version of ECOMSED and this manual have been made possible by the dedicated efforts of Parmeshwar L. Shrestha, B. Nicholas Kim, Quamrul Ahsan and Honghai Li. They have helped conceive, design and implement the model enhancements and worked diligently to debug their (and my) changes. The manual owes its form and content to them. Important contributions to various aspects of ECOMSED have also been made at one time or another by Boris Galperin, H. James Herring, Eugenio Gomez-Reyes, C. Kirk Zeigler, and Richard P. Signell. Finally, the seminal contributions of George L. Mellor must be acknowledged. It was he who first managed to secure funding which made the Princeton Ocean Model a reality.

HydroQual, Inc.

1.0 Introduction

This primer describes the use of a fully integrated three-dimensional hydrodynamic, wave and sediment transport model, ECOMSED. The model is designed to simulate with as much realism as possible time-dependent distributions of water levels, currents, temperature, salinity, tracers, cohesive and noncohesive sediments and waves in marine and freshwater systems. The three ECOMSED sub-models are designed to work in conjunction with one another, with output from one serving as input to another. The same orthogonal curvilinear computational grid structure and underlying numerical solution techniques are utilized for all sub-models. The wave sub-model embedded in ECOMSED utilizes wave parameters to accurately compute the wave-induced bottom friction necessary for calculation of bed shear stresses at the sediment-water interface. ECOMSED uses an orthogonal curvilinear coordinate system, greatly increasing model efficiency in treating irregularly shaped coastlines and in meeting requirements for high resolution at desired locations.

The ECOMSED model is capable of simulating the transport and fate of suspended sediments, dissolved tracers and neutrally-buoyant particles in estuarine and coastal ocean systems. A wide variety of problems concerning water optics and spill tracking can be studied using the model due to the various options built into ECOMSED. Capabilities of the model include: (1) runtime computed (internal) or precomputed (external) hydrodynamics; (2) cohesive and non-cohesive sediment transport; (3) sediment-bound tracer transport (conservative or first-order decay); (4) dissolved tracer transport (conservative or first-order decay); (5) neutrally-buoyant particle tracking; and (6) inclusion of wind wave effects on hydrodynamics and sediment transport. Descriptions of ECOMSED options and capabilities are provided in the following section.

The development of ECOMSED is an ongoing topic of research. The user of this version (1.2) can expect modifications, some of which will be "fixes" to the code and others which will be enhancements to the present water physics and sediment dynamics. Many changes in this primer are planned and some already implemented. Please direct any suggestions and critical comments to *ecomsed-support@hydroqual.com*. All ideas are welcome and many may find themselves in the next version of this primer.

2.0 ECOMSED Model Features

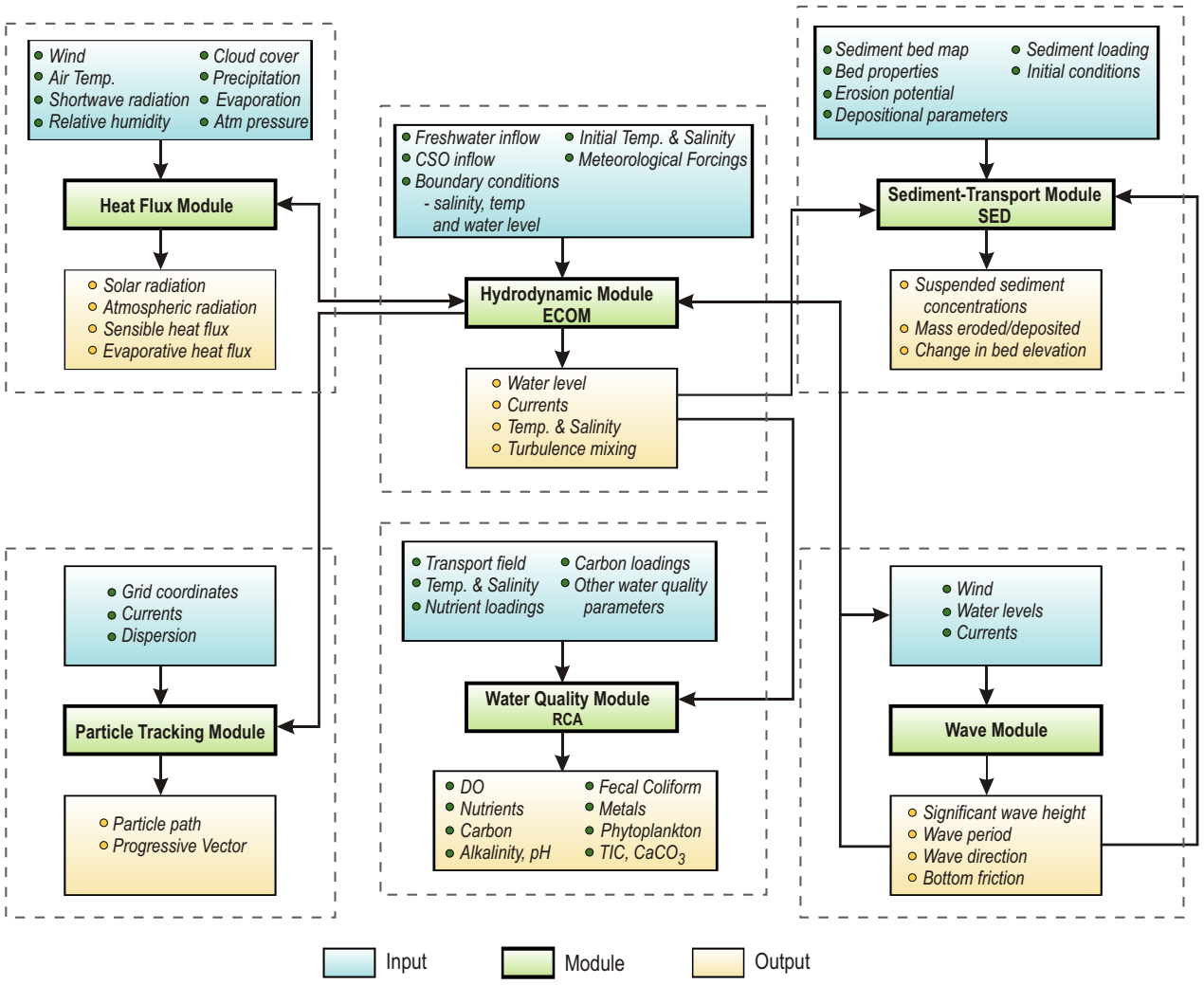
The ECOMSED is a state-of-the-art hydrodynamic and sediment transport model which realistically computes water circulation, temperature, salinity, and mixing and transport, deposition and resuspension of cohesive and non-cohesive sediments. The complete ECOMSED model consists of several modules. These are hydrodynamic module, sediment transport module, wind induced wave module, heat flux module and particle tracking module. Figure 2.1 illustrates the ECOMSED modeling framework. The ECOMSED is also coupled with HydroQual's state-of-the-art water quality model, RCA by a sophisticated and efficient interface. The modules within the ECOMSED modeling framework are linked internally. These modules can be turned on and off by the users depending upon their needs. The ECOMSED modeling framework also allows for linking each module externally. For example, the hydrodynamic module can be run stand alone and transport information can be saved in a separate file. Then the sediment module can be run stand alone using the previously saved transport information, and so is the water quality module, RCA. The following section describes the various features of ECOMSED in detail.

2.1 Internal/External Hydrodynamics

Hydrodynamic simulations are required to provide advection and dispersion information for the water-borne constituent transport algorithms. ECOMSED can use either internal or external hydrodynamic information. When the internal hydrodynamic option is chosen, the ECOM hydrodynamic model, which is built into ECOMSED, runs in parallel with the sediment and tracer transport algorithms. The external hydrodynamic option of ECOMSED allows the model to use previously-generated hydrodynamic information that has been stored in computer files. Simulation of sediment and tracer transport is accomplished by reading hydrodynamic information from the previously-generated computer files. This method has the advantage of reduced computational times when compared to the internal hydrodynamic option. However, care must be taken when using the external option because the previously-generated transport files required to study a particular aquatic system may be too large to handle. In other words, computer storage requirements could limit the temporal length of simulations to the point that the external option cannot be used effectively for a specific problem.

2.2 Sediment Transport

The transport and fate of cohesive and non-cohesive sediments can be simulated with ECOMSED. Resuspension, deposition and transport of cohesive sediments, which are composed of clays, silts and organic material, are simulated using the SED module. The suspended transport of non-cohesive sediments, i.e., fine sands, is calculated using the van Rijn procedure (van Rijn, 1984). The effects of bed armoring due to particle-size heterogeneity can also be included in non-cohesive sediment transport simulations. See Section 6 for a more detailed description of the sediment dynamics included in the cohesive and non-cohesive sediment modules. The sediment transport module can



ECOMSED Modeling Framework

FIGURE 2-1

predict temporal and spatial distributions of: (1) suspended sediment concentrations (cohesive and non-cohesive); (2) sediment bed elevation changes; (3) fluxes at the sediment-water interface; and (4) changes in sediment bed composition. The module can accept as input: spatially-variable sediment bed properties and time-variable sediment loading at river discharges and open boundaries.

2.3 Sediment-bound Tracer Transport

The fate of sediments from a particular source, e.g., river discharge or specific sediment bed location, can be determined using ECOMSED. This type of simulation is accomplished by using a sediment-bound tracer, which is analogous to a hydrophobic contaminant, e.g., organic chemical, heavy metal or radionuclide, that adsorbs to fine-grained sediment particles. However, in these simulations the tracer is permanently adsorbed to the sediment particles; actual hydrophobic contaminants are partially soluble and exist in both particulate and dissolved form, with a high percentage of the contaminant being adsorbed to sediment particles.

The transport and fate of sediment-bound tracers can be simulated for both cohesive and non-cohesive sediments. In addition, the tracer can be conservative or be assigned a first-order decay rate, which would approximate a sediment-bound radionuclide. Of particular importance is the use of a sediment bed model that makes it possible to simulate changes in tracer bed concentrations due to deposition and erosion; temporal and spatial (horizontal and vertical) variations in tracer bed concentrations can be predicted. The bed model can also simulate the effects of bioturbation on tracer mixing in the surficial layer of the bed.

2.4 Dissolved Tracer Transport/Pathogen Fate Model

Simulation of the transport of a dissolved tracer and pathogen can be accomplished using ECOMSED, with the tracer being either conservative or having a first-order decay rate depending on the water column temperature, salinity and insolation rates. This type of calculation can be useful for determining the fate of a water-borne contaminant released from a particular location, e.g., river discharge, offshore diffuser or open boundary. Temporally varying tracer concentrations can be specified for all three types of boundary conditions.

2.5 Particle Tracking

This option allows the tracking of discrete particles that can be released into the aquatic system at various locations. These particles are neutrally-buoyant and conservative. A Lagrangian technique is used to advect the particles and a random-walk procedure is employed to simulate the effects of turbulent diffusion. A complete description of the theory and numerical methods used in the particle tracking module can be found in Zhang (1995).

The particle tracking module can be useful for the simulation of oil spills or studying the trajectories of floating objects. Particles can be released from multiple locations at

variable rates. In addition, each released particle has associated with the time and location of its release, which has been helpful information in previous analyses.

2.6 Wind Waves

Resuspension of sediments due to wind-generated waves is an important source of sediment to the water column in many coastal ocean systems. The effects of wind waves on bottom shear stress, which controls sediment resuspension, can be accounted for by ECOMSED. Temporally and spatially variable wind wave parameters, i.e., mean period, significant wave height and direction, can be calculated using an external wave model (e.g., WAM or HISWA), stored in a computer file and then input to ECOMSED. If wind wave information from an external model is unavailable, an internal wave sub-model, which is based upon shallow water SMB theory (USCOE, 1984), can be used to calculate wave parameters. The internal wave sub-model utilizes empirical formulations which provide approximate estimates of significant wave height and period; this module does not account for spatially-varying wind fields, refraction or wave breaking effects.

Once the wave parameters are specified, the Grant-Madsen wave-current model (Grant and Madsen, 1979) is used to calculate bottom shear stresses due to the interaction of waves and currents. A modified version of the Grant-Madsen model which was developed by Scott Glenn (Glenn and Grant, 1987) is incorporated into this version of ECOMSED. If the internal hydrodynamic option is used, the effect of the wave-current interaction on the bottom roughness coefficient can be calculated by the Grant-Madsen model and then included in the hydrodynamic simulation.

3.0 Hydrodynamic Module

3.1 Introduction

This section of the user manual provides a relatively detailed description of a numerical circulation module. The module belongs to that class of models where model realism is an important goal and addresses mesoscale phenomena, that is activity characterized by 1-100 km length and tidal-30 day time scales commonly observed in estuaries and the coastal ocean [Beardsley and Boicourt, 1981]. The module is a three-dimensional coastal ocean model, incorporating a turbulence closure model to provide a realistic parameterization of the vertical mixing processes. The prognostic variables are the three components of velocity, temperature, salinity, turbulence kinetic energy, and turbulence macroscale. The momentum equations are nonlinear and incorporate a variable Coriolis parameter. Prognostic equations governing the thermodynamic quantities, temperature, and salinity account for water mass variations brought about by highly time-dependent coastal upwelling/downwelling processes as well as horizontal advective processes. Free surface elevation is also calculated prognostically, with only some sacrifice in computational time so that tides and storm surge events can also be simulated. This is accomplished by use of a mode splitting technique whereby the volume transport and vertical velocity shear are solved separately. Other computing variables include density, vertical eddy viscosity, and vertical eddy diffusivity. The module also accommodates realistic coastline geometry and bottom topography.

The hydrodynamic module, ECOM described here is a three-dimensional, time-dependent model developed by Blumberg and Mellor (1980, 1987). This module of ECOMSED, has a long history of successful applications to oceanic, coastal and estuarine waters. Some recent applications of the module include Chesapeake Bay (Blumberg and Goodrich, 1990), New York Bight (Blumberg and Galperin, 1990), Delaware Bay and Delaware River (Galperin and Mellor, 1990a, b), the Gulf Stream Region (Ezer and Mellor, 1992), Massachusetts Bay (Blumberg et al., 1993), Georges Bank (Chen et al., 1995), the Oregon Continental Shelf (Allen et al., 1995), and more recently in New York Bight and New York Harbor (Blumberg et al., 1999) and in Onondaga Lake (Ahsan and Blumburg, 1999). In all of these studies, the predictive capabilities of the module were assessed via extensive comparisons with data and a confidence has been established that the predominant physics is realistically reproduced by the module. A detailed description of the module can be found in the above referenced works.

3.2 The Governing Equations

3.2.1 Dynamic and Thermodynamic Equations

The equations which form the basis of the circulation model describe the velocity and surface elevation fields, and the temperature and salinity fields. Two simplifying approximations are used [Bryan, 1969]; first, it is assumed that the weight of the fluid identically balances the pressure (hydrostatic assumption), and second, density differences are neglected unless the differences are multiplied by gravity (Boussinesq approximation).

Consider a system of orthogonal Cartesian coordinates with x increasing eastward, y increasing northward, and z increasing vertically upwards. The free surface is located at z = η(x,y,t) and the bottom is at z = -H(x,y). If $\vec{V}$ is the horizontal velocity vector with components (U,V) and ∇ the horizontal gradient operator, the continuity equation is:

$$\nabla \cdot \vec{V} + \frac{\partial W}{\partial Z} = 0 \tag{3-1}$$

The Reynolds momentum equations are

$$\frac{\partial U}{\partial t} + \vec{V} \cdot \nabla U + W \frac{\partial U}{\partial z} - fV = -\frac{1}{\rho_o} \frac{\partial P}{\partial x} + \frac{\partial}{\partial z}\left(K_M \frac{\partial U}{\partial z} \right) + F_X \tag{3-2}$$

$$\frac{\partial V}{\partial t} + \vec{V} \cdot \nabla V + W \frac{\partial V}{\partial z} + fU = -\frac{1}{\rho_o} \frac{\partial P}{\partial y} + \frac{\partial}{\partial z}\left(K_M \frac{\partial V}{\partial z} \right) + F_Y \tag{3-3}$$

$$\rho g = -\frac{\partial P}{\partial z} \tag{3-4}$$

with ρ_o the reference density, ρ the in situ density, g the gravitational acceleration, P the pressure, K_M the vertical eddy diffusivity of turbulent momentum mixing. A latitudinal variation of the Coriolis parameter, f, is introduced by use of the β plane approximation.

The pressure at depth z can be obtained by integrating the vertical component of the equation of motion, (3), from z to the free surface η, and is

$$P(x,y,z,t) = P_{atm} + g\rho_o\eta + g\int_z^0 \rho(x,y,z',t)dz' \tag{3-5}$$

Henceforth, the atmospheric pressure, P_{atm} is assumed constant.

The conservation equations for temperature and salinity may be written as

$$\frac{\partial \theta}{\partial t} + \vec{V} \cdot \nabla \theta + W \frac{\partial \theta}{\partial z} = \frac{\partial}{\partial z}\left[K_H \frac{\partial \theta}{\partial z} \right] + F_\theta \tag{3-6}$$

$$\frac{\partial S}{\partial t} + \vec{V} \cdot \nabla S + W \frac{\partial S}{\partial z} = \frac{\partial}{\partial z}\left[K_H \frac{\partial S}{\partial z} \right] + F_s \tag{3-7}$$

where θ is the potential temperature (or in situ temperature for shallow water applications) and S is the salinity. The vertical eddy diffusivity for turbulent mixing of heat and salt is denoted as $K_{H.}$. Using the temperature and salinity, the density is computed according to an equation of state of the form

$$\rho = \rho\,(\theta, S) \tag{3-8}$$

given by Fofonoff [1962]. The potential density is ρ, that is, the density evaluated as a function of potential temperature and salinity but at atmospheric pressure; it provides accurate density information to calculate horizontal baroclinic gradients which enter in the pressure gradient terms and the vertical stability of the water column which enters into the turbulence closure module even in deep water when pressure effects become important.

All of the motions induced by small-scale processes not directly resolved by the model grid (subgrid scale) is parameterized in terms of horizontal mixing processes. The terms F_x, F_y, F_θ and F_S found in (3-2), (3-3), (3-6) and (3-7) represent these unresolved processes and in analogy to molecular diffusion can be written as

$$F_x = \frac{\partial}{\partial x}\left[2A_M \frac{\partial U}{\partial x} \right] + \frac{\partial}{\partial y}\left[A_M \left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x} \right) \right] \tag{3-9a}$$

$$F_y = \frac{\partial}{\partial y}\left[2A_M \frac{\partial V}{\partial y} \right] + \frac{\partial}{\partial x}\left[A_M \left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x} \right) \right] \tag{3-9b}$$

and

$$F_{\theta,s} = \frac{\partial}{\partial x}\left[A_H \frac{\partial(\theta, S)}{\partial x} \right] + \frac{\partial}{\partial y}\left[A_H \frac{\partial(\theta, S)}{\partial y} \right] \tag{3-10}$$

One should note that F_x and F_y are invariant to coordinate rotation. While these horizontal diffusive terms are meant to parameterize subgrid scale processes, in practice the horizontal diffusivities, A_M and A_H, are usually required to damp small-scale computational noise. The forms for A_M and A_H are given in Sectin 8.1.2.

3.2.2 Turbulence Closure

The governing equations contain parameterized Reynolds stress and flux terms which account for the turbulent diffusion of momentum, heat, and salt. The parameterization of turbulence in the module described here is based on the work of Mellor and Yamada [1974].

The vertical mixing coefficients, K_M and K_H, in (3-2), (3-3), (3-6) and (3-7) are obtained by appealing to a second order turbulence closure scheme [Mellor and Yamada, 1982] which characterizes the turbulence by equations for the turbulence kinetic energy, $q^2/2$, and a turbulence macroscale, ℓ, according to,

$$\frac{\partial q^2}{\partial t} + \vec{V}\cdot\nabla q^2 + W\frac{\partial q^2}{\partial z} = \frac{\partial}{\partial z}\left(K_q \frac{\partial q^2}{\partial z}\right) + 2K_M\left[\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right] + \frac{2g}{\rho_o}K_H\frac{\partial \rho}{\partial z} - \frac{2q^3}{B_1\ell} + F_q \tag{3-11}$$

and

$$\frac{\partial\left(q^2\ell\right)}{\partial t} + \vec{V}\cdot\nabla(q^2\ell) + W\frac{\partial\left(q^2\ell\right)}{\partial z} = \frac{\partial}{\partial z}\left[K_q\frac{\partial}{\partial z}(q^2\ell)\right] + \ell E_1 K_M\left[\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right] + \frac{\ell E_1 g}{\rho_o}K_H\frac{\partial \rho}{\partial z} - \frac{q^3}{B_1}\tilde{W} + F_\ell \tag{3-12}$$

where ∇ is the horizontal gradient operator and a wall proximity function is defined as

$$\tilde{W} \equiv 1 + E_2\left(\frac{\ell}{\kappa L}\right)^2 \tag{3-13}$$

and where

$$(L)^{-1} \equiv (\eta - z)^{-1} + (H + z)^{-1} \tag{3-14}$$

Near surfaces it may be shown that both ℓ/κ and L are equal to the distance from the surface (κ = 0.4 is the von Karman constant) so that $\tilde{W} = 1 + E_2$. Far from the surfaces where $\ell << L, \tilde{W} \simeq 1$. The length scale provided by (3-12) is a characteristic length of the turbulent motion at any point in space or time. An alternative to (3-12)

is to use a transport equation for the dissipation rate [Hanjalic and Launder, 1972]. The former approach according to Mellor and Yamada [1982] is more consistent since it uses an equation which describes large-scale turbulence to determine the turbulent macroscale. The terms F_q and F_ℓ in (3-11) and (3-12) are the horizontal mixing and are parameterized analogously to temperature and salinity by using (3-9).

While details of the closure module are rather involved, it is possible to reduce the prescription of the mixing coefficients K_M, K_H, and K_q to the following expressions,

$$K_M \equiv \ell q S_M \tag{3-15a}$$

$$K_H \equiv \ell q S_H \tag{3-15b}$$

$$K_q \equiv \ell q S_q \tag{3-15c}$$

The stability functions, S_M, S_H, and S_q are analytically derived, algebraic relations functionally dependent upon $\partial U/\partial z$, $\partial V/\partial z$, $g\rho_o^{-1}\partial\rho/\partial z$, q and ℓ. These relations derive from closure hypotheses described by Mellor [1973] and summarized by Mellor and Yamada [1982]. Following Galperin et al. [1988] the stability functions are:

$$S_M = \frac{B_1^{-1/3} - 3A_1A_2G_H\left[\left(B_2 - 3A_2\right)\left(1 - \frac{6A_1}{B_1}\right) - 3C_1\left(B_2 + 6A_1\right)\right]}{\left[1 - 3A_2G_H\left(6A_1 + B_2\right)\right]\left(1 - 9A_1A_2G_H\right)} \tag{3-16}$$

$$S_H = \frac{A_2\left(1 - \frac{6A_1}{B_2}\right)}{1 - 3A_2G_H\left(6A_1 + B_2\right)} \tag{3-17}$$

$$Sq = 0.41 * S_M \tag{3-18}$$

and

$$G_H\, n = n - n\left(\frac{N\ell}{q}\right)^2 \tag{3-19a}$$

where

$$N = \left(-\frac{g}{\rho_o}\frac{\partial \rho}{\partial y} \right)^{1/2} \tag{3-19b}$$

is the Brunt-Vaisala frequency. The empirical constants given in Mellor and Yamada (1982) are: (A1, A2, B1, B2, C1, E1, E2) = (0.92, 0.74, 16.6, 10.1, 0.08, 1.8, 1.33), respectively.

3.2.3 Boundary Conditions

The boundary conditions at the free surface, z = η(x,y), are

$$\rho_o K_M \left(\frac{\partial U}{\partial z}, \frac{\partial V}{\partial z} \right) = \left(\tau_{ox}, \tau_{oy} \right) \tag{3-20a}$$

$$\rho_o K_H \left(\frac{\partial \theta}{\partial z}, \frac{\partial S}{\partial z} \right) = \left(\dot{H}, \dot{S} \right) \tag{3-20b}$$

$$q^2 = B_1^{2/3} u_{\tau s}^2 \tag{3-20c}$$

$$q^2 \ell = 0 \tag{3-20d}$$

$$W = U\frac{\partial \eta}{\partial x} + V\frac{\partial \eta}{\partial y} + \frac{\partial \eta}{\partial t} \tag{3-20e}$$

where (τ_{ox}, τ_{oy})is the surface wind stress vector with the friction velocity, $u_{\tau s}$, the magnitude of the vector. It is doubtful that the mixing length goes to zero at a surface containing wind induced waves as suggested by (3-20d). The error is incurred in the near surface layers of thickness of order of the wave height. This is an area where further improvement is necessary. The quantity $B_1^{2/3}$ is an empirical constant (6.51) arising from the turbulence closure relations. The net ocean heat flux is $\dot{H}$ and here $\dot{S} \equiv S(0)[\dot{E} - \dot{P}]/\rho_o$ where $(\dot{E} - \dot{P})$ is the net evaporation-precipitation fresh water surface mass flux rate and S(0) is the surface salinity. On the side walls and bottom of the basin, the normal gradients of θ and S are zero so that there are no advective and diffusive heat and salt fluxes across these boundaries. At the lower boundary (b),

$$\rho_o K_M \left(\frac{\partial U}{\partial z}, \frac{\partial V}{\partial z} \right) = \left(\tau_{bx}, \tau_{by} \right) \tag{3-21a}$$

$$q^2 = B_1^{2/3}\, u_{\tau b}^{\,2} \tag{3-21b}$$

$$q^2 \ell = 0 \tag{3-21c}$$

$$W_b = -U_b \frac{\partial H}{\partial x} - V_b \frac{\partial H}{\partial y} \tag{3-21d}$$

where H(x,y) is the bottom topography and $u_{\tau b}$ is the friction velocity associated with the bottom frictional stress (τ_{bx}, τ_{by}). The bottom stress is determined by matching velocities with the logarithmic law of the wall. Specifically,

$$\vec{\tau}_b = \rho_o C_D |\vec{V}_b| \vec{V}_b \tag{3-22}$$

With value of the drag coefficient C_D given by

$$C_D = \left[\frac{1}{\kappa} \ln\left(H + z_b\right)/z_o\right]^{-2} \tag{3-23a}$$

where z_b and V_b are the grid point and corresponding velocity in the grid point nearest the bottom and κ is the von Karman constant. The final result of (3-22) and (3-23) in conjunction with the turbulent closure derived K_M is that the calculations will yield

$$\vec{V} = \left(\vec{\tau}_b / \rho \kappa u_{\tau b}\right) \ln\left(\frac{H+z}{z_o}\right) \tag{3-23b}$$

in the lower boundary region if enough resolution is provided. In those instances where the bottom boundary layer is not well resolved, it is more appropriate to specify $C_D = 0.0025$. The actual algorithm is to set C_D to the larger of the two values given by (3-23a) and 0.0025. The parameter z_o depends on the local bottom roughness; in the absence of specific information $z_o = 1$ cm is used as suggested by Weatherly and Martin [1978].

3.2.4 Open Lateral Boundary Condition

3.2.4.1 Temperature and Salinity

Open lateral boundary conditions are problematic since one must parameterize the environment exterior to the relevant domain. Two types of open boundaries exist, inflow and outflow. Temperature and salinity are prescribed from data at an inflowing boundary, whereas at outflow boundaries,

$$\frac{\partial}{\partial t}(\theta, S) + U_n \frac{\partial}{\partial n}(\theta, S) = 0 \qquad (3\text{-}23c)$$

is solved where the subscript n is the coordinate normal to the boundary. Turbulence kinetic energy and the macroscale quantity ($q^2\ell$) are calculated with sufficient accuracy at the boundaries by neglecting the advection in comparison with other terms in their respective equations.

The open lateral velocity boundary conditions in some of the applications are computed by using the available hydrographic data in conjunction with a simplified diagnostic model. This type of model uses only geostrophic plus Ekman dynamics and therefore solves a simplified form of the full equations of motion. It does not require a velocity at a reference level but only along a single transect crossing f/H contours. A detailed description of this module can be found in the work by Kantha et al. [1982]. While the normal component of velocity is specified, a free slip condition is used for the tangential component.

3.2.4.2 Water Level Boundary Condition

In developing the ocean circulation module, open boundary conditions that allow long-wave energy (e.g., tides) to enter the open boundaries as well as a means of radiating out longwave energy that impacts the open boundary from the interior of the model domain must be provided. There are a number of radiation boundary conditions that can be utilized to achieve these goals. ECOMSED modeling framework adopts several types of boundary conditions that are discussed below.

3.2.4.2.1 Clamped Boundary Condition

In this type of boundary condition the module uses water level along the boundary grids assigned by the users either from observed data or tidal harmonics. However, this kind of boundary condition is considered rigid and does not allow long wave energy (tides or storm surges) to enter or radiate out of the model domain. For a smaller model domain where wind induced long wave is important to pass through the model boundary, the clamped boundary condition could be problematic.

3.2.4.2.2 Inverted Reid and Bodine Boundary Condition

For longwave to radiate through the boundaries, ECOMSED model utilizes an open boundary condition developed by Reid and Bodine (1968). This condition has the form of

$$\eta = \eta_o + \lambda_t u_n [g / D]^{-1/2} \qquad (3\text{-}24a)$$

where η is the sea level at the open boundary, η_o is the known (assigned) tidal and perhaps low frequency sea level variation at the grid cell, u_n is the model-predicted velocity perpendicular to the open boundary, g is the acceleration due to gravity, and

D is the depth of the grid cell. (The LaGrange multiplier $\lambda_t = 1$ is calculated each time step to allow modification of the sea level due to longwave radiation.) For Inverted Reid and Bodine type of boundary condition, $\lambda_t = 1$. Please note for $\lambda_t = 0$ the formulation provided by Equation (3-24a) gives rise to a condition which is strictly clamped.

3.2.4.2.3 Optimized Clamped Boundary Condition

The optimized clamped bounary condition can be defined by Equation (3-24a). Here the LaGrange multiplier is computed with time based on solving optimization problems that minimize the difference between the model computed values and the "reference" boundary values under certain integral constraints on the open boundary. These constraints represent the energy, momentum, and mass fluxes through the open boundary. Detailed discussion on the optimized boundary conditions can be found in Shulman (1995) and Shulman and Lewis (1994).

3.3 Vertical Coordinate Representation

It has often been noted that the ordinary x,y,z coordinate system has certain disadvantages in the vicinity of large bathymetric irregularities. It is desirable to introduce a new set of independent variables that transforms both the surface and the bottom into coordinate surfaces [Phillips, 1957] called σ-coordinate system which is illustrated in Figure 3-1. The governing external and internal mode equations are transformed from (x,y,z,t) to (x*,y*,σ,t*) coordinates, where

$$x^* = x \quad y^* = y \quad \sigma = \frac{z - \eta}{H + \eta} \qquad t^* = t \tag{3-25}$$

Now let $D \equiv H + \eta$ and apply the chain rule; the following relationships linking derivatives in the old system to those in the new system are obtained:

$$\frac{\partial G}{\partial x} = \frac{\partial G}{\partial x^*} - \frac{\partial G}{\partial \sigma}\left(\frac{\sigma}{D}\frac{\partial D}{\partial x^*} + \frac{1}{D}\frac{\partial \eta}{\partial x^*}\right) \tag{3-26a}$$

$$\frac{\partial G}{\partial y} = \frac{\partial G}{\partial y^*} - \frac{\partial G}{\partial \sigma}\left(\frac{\sigma}{D}\frac{\partial D}{\partial y^*} + \frac{1}{D}\frac{\partial \eta}{\partial y^*}\right) \tag{3-26b}$$

$$\frac{\partial G}{\partial z} = \frac{1}{D}\frac{\partial G}{\partial \sigma} \tag{3-26c}$$

$$\frac{\partial G}{\partial t} = \frac{\partial G}{\partial t^*} - \frac{\partial G}{\partial \sigma}\left(\frac{\sigma}{D}\frac{\partial D}{\partial t^*} + \frac{1}{D}\frac{\partial \eta}{\partial t^*}\right) \tag{3-26d}$$

where G is an arbitrary field available, and σ ranges from $\sigma = 0$ at $z = \eta$ to $\sigma = -1$ at $z = -H$. A new vertical velocity can now be defined

$$\omega \equiv Wn - U\sigma\frac{\partial D}{\partial x^*} + \frac{\partial \eta}{\partial x^*} - V\sigma\frac{\partial D}{\partial y^*} + \frac{\partial \eta}{\partial y^*} - \left(\sigma\frac{\partial D}{\partial t^*} + \frac{\partial \eta}{\partial t^*}\right) \tag{3-27}$$

which transforms the boundary conditions, (3-20e) and (3-21d), into

$$\omega(x^*, y^*, 0, t^*) = 0 \tag{3-28a}$$

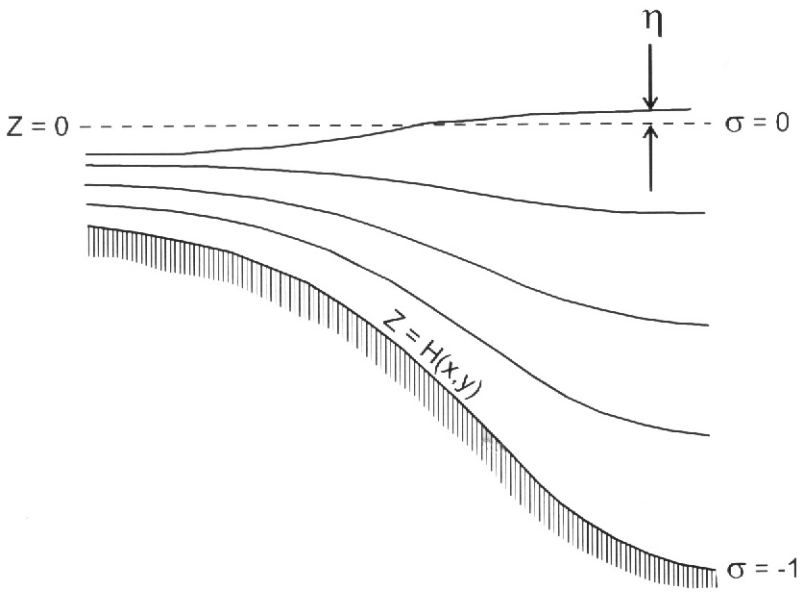
$$\omega(x^*, y^*, -1, t^*) = 0 \tag{3-28b}$$

Also, any vertically integrated quantity, G, for example, now appears as

$$\bar{G} = \int_{-1}^{0} G\, d\sigma \tag{3-29}$$

Equations (3-1), (3-2), (3-3), (3-6), (3-7), (3-11) and (3-12) may now be written as (all asterisks will be dropped for notational convenience)

$$\frac{\partial \eta}{\partial t} + \frac{\partial UD}{\partial x} + \frac{\partial VD}{\partial y} + \frac{\partial \omega}{\partial \sigma} = 0 \tag{3-30}$$



The sigma coordinate system.

FIGURE 3-1

$$\frac{\partial UD}{\partial t}+\frac{\partial U^2D}{\partial x}+\frac{\partial UVD}{\partial y}+\frac{\partial U\omega}{\partial\sigma}-fVD+gD\frac{\partial\eta}{\partial x}$$
$$=\frac{\partial}{\partial\sigma}\left(\frac{K_M}{D}\frac{\partial U}{\partial\sigma}\right)-\frac{gD^2}{\rho_o}\frac{\partial}{\partial x}\int_\sigma^0\rho\,d\sigma$$
$$+\frac{gD}{\rho_o}\frac{\partial D}{\partial x}\int_\sigma^0\sigma\frac{\partial\rho}{\partial\sigma}\,d\sigma+DF_x \tag{3-31}$$

$$\frac{\partial VD}{\partial t}+\frac{\partial UVD}{\partial x}+\frac{\partial V^2D}{\partial y}+\frac{\partial V\omega}{\partial\sigma}+fUD+gD\frac{\partial\eta}{\partial y}$$
$$=\frac{\partial}{\partial\sigma}\left(\frac{K_M}{D}\frac{\partial U}{\partial\sigma}\right)-\frac{gD^2}{\rho_o}\frac{\partial}{\partial y}\int_\sigma^0\rho\,d\sigma$$
$$+\frac{gD}{\rho_o}\frac{\partial D}{\partial y}\int_\sigma^0\sigma\frac{\partial\rho}{\partial\sigma}\,d\sigma+DF_x \tag{3-32}$$

$$\frac{\partial\Theta D}{\partial t}+\frac{\partial\Theta UD}{\partial x}+\frac{\partial\Theta VD}{\partial y}+\frac{\partial\Theta\omega}{\partial\sigma}=\frac{\partial}{\partial\sigma}\left(\frac{K_H}{D}\frac{\partial\Theta}{\partial\sigma}\right)+DF_\Theta \tag{3-33}$$

$$\frac{\partial SD}{\partial t}+\frac{\partial SUD}{\partial x}+\frac{\partial SVD}{\partial y}+\frac{\partial S\omega}{\partial\sigma}=\frac{\partial}{\partial\sigma}\left(\frac{K_H}{D}\frac{\partial S}{\partial\sigma}\right)+DF_S \tag{3-34}$$

$$\frac{\partial q^2D}{\partial t}+\frac{\partial Uq^2D}{\partial x}+\frac{\partial Vq^2D}{\partial y}+\frac{\partial\omega q^2}{\partial\sigma}=\frac{\partial}{\partial\sigma}\left(\frac{K_q}{D}\frac{\partial q^2}{\partial\sigma}\right)$$
$$+\frac{2K_M}{D}\left[\left(\frac{\partial U}{\partial\sigma}\right)^2+\left(\frac{\partial V}{\partial\sigma}\right)^2\right]+\frac{2g}{\rho_o}K_H\frac{\partial\rho}{\partial\sigma}-\frac{2Dq^3}{B_1\ell}+DF_q \tag{3-35}$$

$$\frac{2q^2\ell D}{\partial t}+\frac{\partial Uq^2\ell D}{\partial x}+\frac{\partial Vq^2\ell D}{\partial y}+\frac{\partial \omega q^2}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left(K_{qover}D\frac{\partial q^2\ell}{\partial \sigma}\right)$$
$$+E_1\ell\left\{\frac{K_M}{D}\left[\left(\frac{\partial U}{\partial \sigma}\right)^2+\left(\frac{\partial V}{\partial \sigma}\right)^2\right]+\frac{qE^3}{\rho_o}K_H\frac{\partial \rho}{\partial \sigma}\right\}-\frac{Dq^3}{B_1}\tilde{W}+DF \tag{3-36}$$

The horizontal viscosity and diffusion terms are defined according to:

$$F_x\equiv\frac{\partial D\hat{t}_{xx}}{\partial x}+\frac{\partial}{\partial y}\left(D\hat{\tau}_{yx}\right) \tag{3-37}$$

$$F_y\equiv\frac{\partial D\hat{\tau}_{yy}}{\partial y}+\frac{\partial}{\partial x}\left(D\hat{\tau}_{xy}\right) \tag{3-38}$$

with

$$\hat{\tau}_{xx}=2A_M\left[\frac{\partial U}{\partial x}\right] \tag{3-39}$$

$$\hat{\tau}_{xy}=\hat{\tau}_{yx}=A_M\left[\frac{\partial U}{\partial y}+\frac{\partial V}{\partial y}\right] \tag{3-40}$$

$$\hat{\tau}_{yy}=2A_M\left[\frac{\partial V}{\partial y}\right] \tag{3-41}$$

Also,

$$F_{\theta_i}\equiv\frac{\partial D\hat{q}_x}{\partial x}+\frac{\partial D\hat{q}_y}{\partial y} \tag{3-42}$$

$$\hat{q}_x=A_H\left[\frac{\partial \theta_i}{\partial x}\right] \tag{3-43}$$

$$\hat{q}_y=A_H\left[\frac{\partial \theta_i}{\partial y}\right]^{00} \tag{3-44}$$

where θ_i now represents θ, S, q^2 and $q^2\ell$.

Mellor and Blumberg [1985] have shown that the conventional model for horizontal diffusion is incorrect when bottom topographical slopes are large. Horizontal mixing coefficient A_m and A_H for both momentum and heat/salinity are parameterized suggested by Smagorinsky (963) as described in Section 3.5.2.

3.4 Mode Splitting Technique

The equations governing the dynamics of coastal, estuarine and lake circulation contain propagation of fast moving external gravity waves and slow moving internal gravity waves. It is desirable in terms of computer economy to separate out vertically integrated equations (external mode) from the vertical structure equations (internal mode). This technique, known as mode splitting [see Simons, 1974; Madala and Piacsek, 1977] permits the calculation of the free surface elevation with little sacrifice in computational time by solving the volume transport separately from the vertical velocity shear.

The volume transport, external mode equations are obtained by integrating the internal mode equations over the depth, thereby eliminating all vertical structure. By integrating (3-30) from $\sigma = -1$ to $\sigma = 0$ and using the boundary conditions (3-28a,b) an equation for the surface elevation can be written as

$$\frac{\partial \eta}{\partial t} + \frac{\partial \overline{U}D}{\partial x} + \frac{\partial \overline{V}D}{\partial y} = 0 \tag{3-45}$$

and the momentum equations become upon vertical integration

$$\begin{aligned} &\frac{\partial \overline{U}D}{\partial t} + \frac{\partial \overline{U}^2 D}{\partial x} + \frac{\partial \overline{UV}D}{\partial y} - f\overline{V}D + gD\frac{\partial \eta}{\partial x} - D\overline{F}_x = -\overline{wu}(0) \\ &\quad + \overline{wu}(-1) - \frac{\partial \overline{DU'^2}}{\partial x} - \frac{\partial \overline{DU'V'}}{\partial y} - \frac{gD^2}{\rho_o}\frac{\partial}{\partial x}\int_{-1}^{o}\int_{\sigma}^{o} \rho\, d\sigma' d\sigma \\ &\quad + \frac{gD}{\rho_o}\frac{\partial D}{\partial x}\int_{-1}^{o}\int_{\sigma}^{o} \sigma' \frac{\partial \rho}{\partial \sigma}\, d\sigma' d\sigma \end{aligned} \tag{3-46}$$

$$\frac{\partial \overline{V}D}{\partial t}+\frac{\partial \overline{UV}D}{\partial x}+\frac{\partial \overline{V}^2D}{\partial y}+f\overline{U}D+gD\frac{\partial \eta}{\partial y}-D\overline{F}_y=-\overline{wv}(0)$$
$$+\overline{wv}(-1)-\frac{\partial D\overline{U'V'}}{\partial x}-\frac{\partial \overline{DV'^2}}{\partial y}-\frac{gD^2}{\rho_o}\frac{\partial}{\partial y}\int_{-1}^{o}\int_{\sigma}^{o}\rho\, d\sigma' d\sigma \qquad (3\text{-}47)$$
$$+\frac{gD}{\rho_o}\frac{\partial D}{\partial y}\int_{-1}^{o}\int_{\sigma}^{o}\sigma'\frac{\partial \rho}{\partial \sigma'}d\sigma' d\sigma$$

where the pressure has been obtained from (3-5) and the vertically integrated velocities are defined as

$$(\overline{U},\overline{V})\equiv\int_{-1}^{0}(U,V)\,d\sigma \qquad (3\text{-}48)$$

The wind stress components are $-\overline{wu}(0)$, and $-\overline{wv}(0)$, and the bottom stress components are $-\overline{wu}(-1)$ and $-\overline{wv}(-1)$. The terms in (3-46) and (3-47) involving U'^2, $U'V'$, and V'^2 represent vertical averages of the cross-products of the velocity departures from the vertically integrated (average) velocity and are often denoted as the dispersion terms. Thus

$$\left(\overline{U'^2},\overline{V'^2},\overline{U'V'}\right)=\int_{-1}^{o}\left(U'^2,V'^2,U'V'\right)d\sigma \qquad (3\text{-}49)$$

where $(U',V')=(U-\overline{U},V-\overline{V})$. The quantities $\overline{F}_x$ and $\overline{F}_y$ are vertical integrals of the horizontal momentum diffusion and are defined according to

$$D\overline{F}_x=\frac{\partial}{\partial x}\left(2A_M\frac{\partial \overline{U}D}{\partial x}\right)+\frac{\partial}{\partial y}A_M\left(\frac{\partial \overline{U}D}{\partial y}+\frac{\partial \overline{V}D}{\partial x}\right) \qquad (3\text{-}50)$$

$$D\overline{F}_y=\frac{\partial}{\partial y}\left(2A_M\frac{\partial \overline{V}D}{\partial y}\right)+\frac{\partial}{\partial x}A_M\left(\frac{\partial \overline{U}D}{\partial y}+\frac{\partial \overline{V}D}{\partial x}\right) \qquad (3\text{-}51)$$

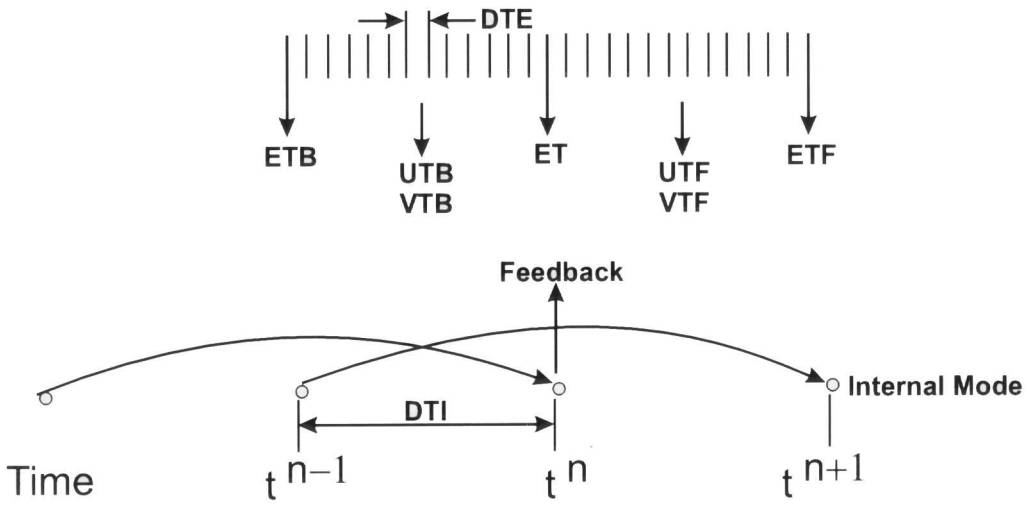
The computational strategy is to solve equations for the external mode, the shallow water wave equations (3-45), (3-46), and (3-47), with a short time step to resolve tidal motions. The external mode solutions are obtained with the terms on the right-hand side of (3-46) and (3-47) held fixed in time and after a large number of time steps, of the order of 100, an internal mode calculation is carried out. The external mode provides $\partial\eta/\partial x$ and $\partial\eta/\partial y$ for insertion into the internal mode equations, (3-30) through (3-36), which are then solved with a much longer time step. Once the vertical

structure has been determined, the terms on the right-hand side (3-46) and (3-47) are updated and another external mode solution begins. In future simulations, the advective and diffusive terms in (3-46) and (3-47) will be supplied by the internal mode. Figure 3-2 illustrates the time stepping process for the external and internal mode.

The external mode equations have not been subtracted from the original equations (3-30) and (3-32) to form the more conventional internal mode set as, for example, in Bryan [1969] and Wang [1982]. Consequently there may be a slow tendency for the vertical integral of the internal mode velocities to differ from the external mode velocities. This arises because of different truncation errors in each mode. To insure against accumulated mismatch, the vertical mean of the internal velocity is replaced at every time step by the external mode velocity.

3.5 Orthogonal Curvilinear Coordinate System Transformation

An important advantage of the present model over that used earlier is the use of a horizontal, orthogonal, curvilinear coordinate system. The full set of the equations in given in Blumberg and Herring (1987); for the present version of the primer only the internal mode equations are given. These equations in the mass flux conservative form are:



A simplified illustration of the interaction of the
External Mode and the Internal Mode

FIGURE 3-2

The Continuity Equation

$$h_1 h_2 \frac{\partial \eta}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 U_1 D) + \frac{\partial}{\partial \xi_2}(h_1 U_2 D) + h_1 h_2 \frac{\partial \omega}{\partial \sigma} = 0 \qquad (3\text{-}52a)$$

where:

$$\omega = W - \frac{1}{h_1 h_2}\left[h_2 U_1 \left(\sigma \frac{\partial D}{\partial \xi_1} + \frac{\partial \eta}{\partial \xi_1} \right) + h_1 U_2 \left(\sigma \frac{\partial D}{\partial \xi_2} + \frac{\partial \eta}{\partial \xi_2} \right) \right]$$

$$- \left(\sigma \frac{\partial D}{\partial t} + \frac{\partial \eta}{\partial t} \right) \qquad (3\text{-}52b)$$

Free Surface Equation
The Reynolds Equations

$$\frac{\partial (h_1 h_2 D U_1)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 D U_1^2) + \frac{\partial}{\partial \xi_2}(h_1 D U_1 U_2) + h_1 h_2 \frac{\partial (\omega U_1)}{\partial \sigma}$$

$$+ D U_2 \left(- U_2 \frac{\partial h_2}{\partial \xi_1} + U_1 \frac{\partial h_1}{\partial \xi_2} - h_1 h_2 f \right)$$

$$= - g D h_2 \left(\frac{\partial \eta}{\partial \xi_1} + \frac{\partial H_o}{\partial \xi_1} \right) - \frac{g D^2 h_2}{\rho_o} \int_\sigma^o \left[\frac{\partial \rho}{\partial \xi_1} - \frac{\sigma}{D} \frac{\partial D}{\partial \xi_1} \frac{\partial \rho}{\partial \sigma} \right] d\sigma$$

$$- D \frac{h_2}{\rho_o} \frac{\partial P_a}{\partial \xi_1} + \frac{\partial}{\partial \xi_1}\left(2 A_M \frac{h_2}{h_1} D \frac{\partial U_1}{\partial \xi_1} \right) + \frac{\partial}{\partial \xi_2}\left(A_M \frac{h_1}{h_2} D \frac{\partial U_1}{\partial \xi_2} \right)$$

$$+ \frac{\partial}{\partial \xi_2}\left(A_M D \frac{\partial U_2}{\partial \xi_1} \right) + \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma}\left(K_M \frac{\partial U_1}{\partial \sigma} \right)$$

(3-53)

$$\frac{\partial(h_1 h_2 D U_2)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 D U_1 U_2) + \frac{\partial}{\partial \xi_2}(h_1 D U_2^2) + h_1 h_2 \frac{\partial(\omega U_2)}{\partial \sigma}$$

$$+ D U_1 \left(- U_1 \frac{\partial h_1}{\partial \xi_2} + U_2 \frac{\partial h_2}{\partial \xi_1} + h_1 h_2 f \right)$$

$$= - gDh_1 \left(\frac{\partial \eta}{\partial \xi_2} + \frac{\partial H_o}{\partial \xi_2} \right) - \frac{gD^2 h_1}{\rho_o} \int_\sigma^o \left[\frac{\partial \rho}{\partial \xi_2} - \frac{\sigma}{D} \frac{\partial D}{\partial \xi_2} \frac{\partial \rho}{\partial \sigma} \right] d\sigma$$

$$- D \frac{h_1}{\rho_o} \frac{\partial P_a}{\partial \xi_2} + \frac{\partial}{\partial \xi_2} \left(2A_M \frac{h_1}{h_2} D \frac{\partial U_2}{\partial \xi_2} \right) + \frac{\partial}{\partial \xi_1} \left(A_M \frac{h_2}{h_1} D \frac{\partial U_2}{\partial \xi_1} \right)$$

$$+ \frac{\partial}{\partial \xi_1} \left(A_M D \frac{\partial U_1}{\partial \xi_2} \right) + \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma} \left(K_M \frac{\partial U_2}{\partial \sigma} \right)$$

(3-54)

Transport of Temperature

$$h_1 h_2 \frac{\partial(\theta D)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 U_1 \theta D) + \frac{\partial}{\partial \xi_2}(h_1 U_2 \theta D) + h_1 h_2 \frac{\partial(\omega \theta)}{\partial \sigma}$$

$$= \frac{\partial}{\partial \xi_1} \left(\frac{h_2}{h_1} A_H D \frac{\partial \theta}{\partial \xi_1} \right) + \frac{\partial}{\partial \xi_2} \left(\frac{h_1}{h_2} A_H D \frac{\partial \theta}{\partial \xi_2} \right) + \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma} \left(K_H \frac{\partial \theta}{\partial \sigma} \right)$$

(3-55)

Transport of Salinity

$$h_1h_2\frac{\partial(SD)}{\partial t}+\frac{\partial}{\partial\xi_1}(h_2U_1SD)+\frac{\partial}{\partial\xi_2}(h_1h_2SD)+h_1h_2\frac{\partial(\omega S)}{\partial\sigma}$$

$$=\frac{\partial}{\partial\xi_1}\left(\frac{h_2}{h_1}A_HD\frac{\partial S}{\partial\xi_1}\right)+\frac{\partial}{\partial\xi_2}\left(\frac{h_1}{h_2}A_HD\frac{\partial S}{\partial\xi_2}\right)+\frac{h_1h_2}{D}\frac{\partial}{\partial\sigma}\left(K_H\frac{\partial S}{\partial\sigma}\right) \tag{3-56}$$

Transport of Turbulent Kinetic Energy

$$h_1h_2\frac{\partial(q^2D)}{\partial t}+\frac{\partial}{\partial\xi_1}(h_2U_1Dq^2)+\frac{\partial}{\partial\xi_2}(h_1U_2Dq^2)\,h_1h_2\frac{\partial(\omega q^2)}{\partial\sigma}$$

$$=h_1h_2\left\{\frac{2K_M}{D}\left[\left(\frac{\partial U_1}{\partial\sigma}\right)^2+\left(\frac{\partial U_2}{\partial\sigma}\right)^2\right]+\frac{2g}{\rho_o}K_H\frac{\partial\rho}{\partial\sigma}-\frac{2q^3D}{\Lambda_1}\right\}$$

$$+\frac{\partial}{\partial\xi_1}\left(\frac{h_2}{h_1}A_HD\frac{\partial q^2}{\partial\xi_1}\right)+\frac{\partial}{\partial\xi_2}\left(\frac{h_1}{h_2}A_HD\frac{\partial q^2}{\partial\xi_2}\right)+\frac{h_1h_2}{D}\frac{\partial}{\partial\sigma}\left(K_q\frac{\partial q^2}{\partial\sigma}\right) \tag{3-57}$$

Turbulent Macroscale

$$h_1h_2\frac{\partial(q^2\lambda D)}{\partial t}+\frac{\partial}{\partial\xi_1}(h_2U_1Dq^2\lambda)+\frac{\partial}{\partial\xi_2}(h_1U_2Dq^2\lambda)+h_1h_2\frac{\partial(\omega q^2\lambda)}{\partial\sigma}$$

$$=h_1h_2\left\{\frac{\lambda E_1K_M}{D}\left[\left(\frac{\partial U_1}{\partial\sigma}\right)^2+\left(\frac{\partial U_2}{\partial\sigma}\right)^2\right]+\frac{\lambda E_1g}{\rho_o}K_H\frac{\partial\rho}{\partial\sigma}-\frac{q^3D}{B_1}\tilde{w}\right\}$$

$$+\frac{\partial}{\partial\xi_1}\left(\frac{h_2}{h_1}A_HD\frac{\partial(q^2\lambda)}{\partial\xi_1}\right)+\frac{\partial}{\partial\xi_2}\left(\frac{h_1}{h_2}A_HD\frac{\partial(q^2\lambda)}{\partial\xi_2}\right)$$

$$+ \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma} \left(K_q \frac{\partial (q^2 \lambda)}{\partial \sigma} \right) \tag{3-58}$$

where ξ_1 and ξ_2 are arbitrary horizontal curvilinear orthogonal coordinates.

3.6 Surface Heat Flux

The energy content in lakes, reservoirs, estuaries, and coastal and oceanic water bodies is primarily governed by the surface heat energy exchanges. Measurements of heat fluxes such as solar radiations, atmospheric radiation, sensible heat and latent heat fluxes are very difficult and costly to make and are often parameterized to obtain the fluxes, using the most commonly available meteorological data. The processes that control the heat exchange between the water and atmosphere are well documented (Large and Pond, 1982; Rosati and Miyakoda, 1988; Cole and Buchak, 1994; Ahsan and Blumberg, 1999). All of these works relied mostly on the bulk formulae to evaluate the components of the heat budget. It is important to note here that most of bulk formulae, available in literature, for calculations of radiative fluxes are based on basically the same principles and generally agree with one another in general patterns of temporal and spatial variations of fluxes. However, significant differences in their magnitudes exist depending on the time period of the year and latitudinal position of the study area.

Estimation of net heat flux requires a great deal of judgement in choosing the bulk formulae which are dependent on meteorological parameters like cloud cover, relative humidity, air temperature, winds, water surface temperature etc. Computations of four major heat flux components such as short wave solar radiations, longwave atmospheric radiations, sensible heat and latent heat fluxes have been introduced in ECOM code using three formulations based on the works of Ahsan and Blumberg (1999), Rosati and Miyakoda (1988) and Large and Pond (1982). Users may choose either of these three formulations by choosing heat flux options A&BFLX, R&BFLX, and L&PFLX respectively (see data entry section). Table 3-1 describes the equations to compute the individual heat flux component using these three options. It has been demonstrated in literature that option A&BFLX has more success in simulating heat budget in inland lakes, reservoirs and estuarine systems. The latter two options are described as more appropriate for oceanic environments. The users may apply their judgement to choose these options depending on the nature of their applications.

Table 3-1. Heatflux Formulations in Ecom Model

	A and BFLX	R and MFLX	L and PFLX
Solar Radiation* (H_s)	users measured data	users measured data	users measured data
Atmospheric Radiation (H_a)	$\varepsilon\sigma\left\{\begin{matrix}\left(9.37\text{x}10^{-6}T_a^6\right)\\ \left(1+0.17C^2\right)\end{matrix}\right\}-T_s^4$	$\varepsilon\sigma T_a^4\left(0.39-0.05e_a^{1/2}\right)\left(1-0.8C\right)+4\varepsilon\sigma T_s^3\left(T_s-T_a\right)$	$\left\{\begin{matrix}\varepsilon\sigma T_s^4\left(0.39-0.05e_s^{1/2}\right)\\ +4\varepsilon\sigma T_s^3\left(T_s-T_a\right)\end{matrix}\right\}\left(1-0.62C^2\right)$
Sensible Heatflux (H_c)	$C_c f(w)\left(T_s-T_a\right)$	$C_T W\left(T_s-T_a\right)$	$C_T U_z\left(T_s-\theta_z\right)$
Evaporative Heatflux (H_e)	$f(w)\left(e_s-e_a\right)$	$C_E W\left(e_s-re_a\right)0.621/P$	$C_E U_z\left(\theta_s-\theta_z\right)$
References	Ahsan & Blumberg (1999) (Cole & Buchak (1994))	Rosati & Miyakoda (1988)	Large & Pond (1982)

*In case field measurements are not available, the model computes solar radiation based on:

$H_s = Q_{TOT}(1\text{-}0.62C + 0.001\partial\beta)(1\text{-}\alpha)$; $Q_{TOT} = Q_{DIR} + Q_{DIFF}$; $Q_{DIR} = Q_o T^{secz}$;

$Q_{DIFF} = [(1 - A_a)Q_o - Q_{DIR}]/2$; $Q_o = \frac{J_o}{a^2}\,CsozD_F(\phi,\lambda)$

(See Rosati and Miyakoda (1988) for definition of parameters.)

Definition of Parameters

ϵ	Emmissivity of water (0.97)	CT	Bulk transfer coefficient for conductive heat flux
σ	Stephen-Boltzman Constant ($5.67 * 10^{-8}$) ($WM^{-2}K^{-4}$)	CE	Bulk transfer coefficient for evaporative heat flux
T_s	Water surface temperature in ºK	W	Windspeed in m/s
T_a	Air temperature in ºK	θ	Virtual air temperature
$e_s(Ta,Ts)$	Saturated vapor pressure in mbar at air temperature T_a and sea surface temperature T_s	f(w)	Windspeed function ($6.9 + 0.34\ W^2$) in w m^{-2} $mbar^{-1}$
		P	Barometric pressure in mbar
		R	relative humidity
C	Cloud cover fraction (0 - 1.0)		

4.0 Tracer/Pathogen Fate Module

Abundances of enteric organisms in natural systems are determined by rates of inputs (loads) to the bay from outfalls and shoreline sources, transport due to currents, and dispersion and loss processes that include phototoxicity, temperature, salinity, predation or die-off and settling. These factors may be present in varying degrees depending on the specific situation and locations. The resultant distribution of the organism concentration will then reflect the decay (or growth) of the organism as a function of spatial and temporal scales of the water body. The governing equation is the classical time-dependent three-dimensional mass transport equation with sink terms representing the various loss processes as described below:

$$\frac{\partial C}{\partial t}+\frac{\partial C u}{\partial x}+\frac{\partial C v}{\partial y}+\frac{\partial C w}{\partial z}=\frac{\partial}{\partial z}\left(K_H \frac{\partial C}{\partial z}\right)+F_c+kC$$

Where, C is the concentration of pathogen organism, k is the die-off coefficient or decay rate, Fc represents the horizontal diffusion of pathogen bacteria. All other terms as same as described earlier.

Populations of coliforms exhibit a number of mortality patterns in laboratory experiments when wastewater is diluted by water in an effort to simulate the discharge of a waste into a receiving water (Mancini, 1978). These patterns can be classified as first order mortality of coliforms, initial population increases followed by first order mortality and either of the above patterns, followed by a reduced rate of mortality as time increases and population levels are reduced. Initial estimates of the die-off coefficient were developed from special laboratory studies and from values reported in the literature (Mancini, 1978). Laboratory studies indicated that the coliforms bacteria die-off rate (at 20°C) in seawater varied between 0.8/day and 1.4/day. These rates are approximately equal to die-off rates developed in other modeling calibration analyses. These laboratory values confirmed the following functional relationship of the coliforms bacteria die-off rate:

$$k=k_d+k_i+k_s$$

k_d = rate coefficient for death in the dark; includes effects of temperature, salinity and predation (d^{-1}).
k_i = rate coefficient for death as mediates by irradiance (d^{-1}).
k_s = rate coefficient for sedimentation loss (d^{-1}).

k_d is defined by Maveim (1978) and also reported by Thomann and Mueller (1987).

$$k_d = (0.80 + 0.006 * (\% \text{ of seawater})) \times \theta^{T-20}$$

here θ = 1.07 is dimensionless constant which describes the relationship between the rate coefficient and temperature

% of seawater for 22 ppt, for example is 22/35 x 100 (sea water 35 ppt) = 62.85%

$$k_i = \frac{\alpha I_o}{k_e z}\left[1 - e^{-k_e z}\right]$$

k_i = coliform mortality rate due to light (d^{-1})
α = proportionality constant

I_o = average daily solar (surface) radiation (langleys/hr)

Note:

1 watt/m^2 = 2.066115 langley/day
= 0.086088 langleys/hr.
K_e = light extinction coefficient (m^{-1})
z = depth of water at which the decay rate is applied
α = 1

$$k_s = \frac{\nu_s}{H} = \frac{\nu_s}{z}$$

ν_s = net loss rate in m/day of the particulate bacterial forms.
z, H = water depth at which the rate is applied.

ν_s varies from 1 · 17 to 2 · 4 m/day for small (0.45-10 μm) and large (>10 μm), grain sizes, respectively.

5.0 Particle Tracking Module

The movement of particles can be determined by exploiting the equivalency between tracking particles and solving a mass transport equation for a conservative substance (Thompson and Gelhar 1990). Following Dimou and Adams (1993), a random-walk particle tracking scheme has been designed which calculates the displacement of particles as the sum of an advective deterministic component and an independent, random Markovian component which statistically approximates the dispersion characteristics of the environment. By relating the advective and Markovian components to the appropriate terms in a conservation equation, a technique has been designed where a distribution of particles will turn out to be the same as that concentration resulting from the solution of the conservation equation.

In a three dimensional environment, a conservative substance is transported under the influence of advection and dispersion processes. The solution for this transport problem is commonly based on the mass balance equation. Introducing the *s* transformation in the vertical:

$$\sigma = \frac{z - \eta}{H + \eta} \tag{5-1}$$

where H(x,y) is the water depth, η(x,y) is the surface elevation and D = H + η, the transport equation for a conservative tracer in an orthogonal curvilinear coordinate system (ξ_1, ξ_2, σ) can be written as (Zhang, 1995),

$$h_1 h_2 \frac{\partial (DC)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 U_1 DC) + \frac{\partial}{\partial \xi_2}(h_1 U_2 DC) + h_1 h_2 \frac{\partial (\omega C)}{\partial \sigma} = \frac{\partial}{\partial \xi_1}\left(\frac{h_2}{h_1} A_H D \frac{\partial C}{\partial \xi_1}\right) + \frac{\partial}{\partial \xi_2}\left(\frac{h_1}{h_2} A_H D \frac{\partial C}{\partial \xi_2}\right) + \frac{h_1 h_2}{D}\frac{\partial}{\partial \sigma}\left(K_H \frac{\partial C}{\partial \sigma}\right) \tag{5-2}$$

where

$$\omega = W - \frac{1}{h_1 h_2}\left[h_2 U_1\left(\sigma \frac{\partial D}{\partial \xi_1} + \frac{\partial \eta}{\partial \xi_1}\right) + h_1 U_2\left(\sigma \frac{\partial D}{\partial \xi_2} + \frac{\partial \eta}{\partial \xi_2}\right)\right] - \left(\sigma \frac{\partial D}{\partial t} + \frac{\partial \eta}{\partial t}\right) \tag{5-3}$$

C is the concentration, h_1 and h_2 are the metrics of the unit grid cell in the ξ_1 and ξ_2 directions, and U1 and U2 are the velocity components along the ξ_1 and $\xi_2$directions. Adding:

$$\frac{\partial}{\partial\xi_1}\left[\frac{\partial}{\partial\xi_1}\left(\frac{A_H}{h_1^2}h_1h_2D\right)C\right]+\frac{\partial}{\partial\xi_2}\left[\frac{\partial}{\partial\xi_2}\left(\frac{A_H}{h_2^2}h_1h_2D\right)C\right] \quad (5\text{-}4)$$
$$+\frac{\partial}{\partial\sigma}\left[\frac{\partial}{\partial\sigma}\left(\frac{K_H}{D^2}h_1h_2D\right)C\right]$$

on both sides of Equation (5-2) and rearranging it, the transport equation becomes,

$$\frac{\partial}{\partial t}(h_1h_2DC)+\frac{\partial}{\partial\xi_1}\left\{\left[\frac{U_1}{h_1}+\frac{1}{h_1h_2D}\frac{\partial}{\partial\xi_1}\left(\frac{A_H}{h_2^2}h_1h_2D\right)\right]h_1h_2DC\right\}$$
$$+\frac{\partial}{\partial\xi_2}\left\{\left[\frac{U_2}{h_2}+\frac{1}{h_1h_2D}\frac{\partial}{\partial\xi_2}\left(\frac{A_H}{h_2^2}h_1h_2D\right)\right]h_1h_2DC\right\} \quad (5\text{-}5)$$
$$+\frac{\partial}{\partial\sigma}\left\{\left[\frac{\omega}{D}+\frac{1}{h_1h_2D}\frac{\partial}{\partial\sigma}\left(\frac{K_H}{D_2}h_1h_2D\right)\right]h_1h_2DC\right\}$$
$$=\frac{\partial}{\partial\xi_1^2}\left(\frac{A_H}{h_1^2}h_1h_2DC\right)+\frac{\partial}{\partial\xi_2^2}\left(\frac{A_H}{h_1^2}h_1h_2DC\right)+\frac{\partial^2}{\partial\sigma^2}\left(\frac{K_H}{D^2}h_1h_2DC\right)$$

Representing the conservative tracer concentration by a collection of particles, the transport problem can also be solved by particle tracking models (Dimou, 1989; Dimou and Admas 1993; Tompson and Gelhar, 1990). As described by those previous studies, the displacement of a particle in a random-walk model is governed by the non-linear Langevin equation (Gardinar, 1985)

$$\frac{\vec{dX}}{dt} = A(\vec{X}t) + B\left(\vec{X},t\right)Z_n \quad (5\text{-}6)$$

where $\vec{X}(t)$, $A(\vec{X},t)$ *and* $B(\vec{X}t)$ are vectors, $\vec{X}(t)$ defines the position of a particle, $A(\vec{X},t)$ is the deterministic forces that advect particles, $B(\vec{X},t)$ represents the random forces that lead to particle diffusion (Solomon et al 1994), and Z(t) is a vector of the independent random numbers with zero mean and unit variance.

If $f = f\left(\vec{X},t|\vec{X}_0t_0\right)$ is defined as the conditional probability density function for $\vec{X}(t)$ of particles whose initial position at t_0 is $\vec{X}_0$, the number density will satisfy the Ito-Fokker-Planck equation (Kinzelbach, 1988; Tompson and Gelhar, 1990) in the limit as the number of particles gets very large and the time step used to solve the conservation equation gets very small.

$$\frac{\partial f}{\partial t}+\frac{\partial}{\partial \vec{X}}(Af)=\nabla^2\left(\frac{1}{2}BB^T f\right) \tag{5-7}$$

Therefore, the transport equation (5-5) is equivalent to the Ito-Fokker-Planck equation (5-7) if $f = h_1h_2DC$,

$$A \equiv \begin{bmatrix} \dfrac{U_1}{h_1}+\dfrac{1}{h_1h_2D}\dfrac{\partial}{\partial\xi_1}\left(\dfrac{A_H}{h_1^2}h_1h_2D\right) \\ \dfrac{U2}{h_2}+\dfrac{1}{h_1h_2D}\dfrac{\partial}{\partial\xi_2}\left(\dfrac{A_H}{h_2^2}h_1h_2D\right) \\ \dfrac{\omega}{D}+\dfrac{1}{h_1h_2D}\dfrac{\partial}{\partial\sigma}\left(\dfrac{K_H}{D^2}h_1h_2D\right) \end{bmatrix} \tag{5-8}$$

and

$$\frac{1}{2}BB^T \equiv \begin{bmatrix} \dfrac{A_H}{h_1^2} & 0 & 0 \\ 0 & \dfrac{A_H}{h_2^2} & 0 \\ 0 & 0 & \dfrac{K_H}{D^2} \end{bmatrix} \tag{5-9}$$

Thus, $A(\vec{X},t), B(\vec{X},t)$ in Equation (5-6) can be determined and the position $\vec{X}(t)$ of each particle can be calculated.

The numerical algorithm used in the solution of Equation (5-6) is based on the same grid structure and interpolation schemes that are built into ECOMSED. To ensure that the tracking methodology is correct, tests comparing the methodology with analytical solutions were conducted (Zhang 1995). The tests involve long straight channels, with flat and sloping bottoms and circular channels with open and closed lateral boundaries. The methodology was able to obtain the correct answer for all of these test cases.

6.0 Sediment Transport Module

6.1 Introduction

The SED module is HydroQual's state-of-the-art three-dimensional sediment transport model. It realistically simulates cohesive and noncohesive sediments in a variety of aquatic systems (e.g., lakes, rivers, estuaries, bays and coastal waters). There are two different sediment transport modeling frameworks incorporated in ECOMSED. In the mid 1990s, concepts of cohesive sediment resuspension, settling and consolidation (Lick et al., 1994) were incorporated within the ECOM modeling framework to create ECOMSED (SEDZL). Over a period of several years, significant modifications were made to ECOMSED to include generalized open boundary conditions, tracers, better bottom shear stresses through a submodel for bottom boundary layer physics, surface wind-wave models, noncohesive sediment transport, and dissolved and sediment-bound tracer capabilities. ECOMSED have been used in a number of sediment transport studies, including: Pawtuxet River in Rhode Island (Ziegler and Nisbet, 1994), Watts Bar Reservoir in Tennessee (Ziegler and Nisbet, 1995), Lavaca Bay in Texas (HydroQual, 1998), Tannery Bay in Michigan (Cannelton Industries, 1998), and Green Bay in Wisconsin (Shrestha et al., 2000). In 2007, peer-reviewed sediment transport model (SEDZLJ) (Jones and Lick, 2001) was incorporated into HydroQual's hydrodynamic model framework, ECOMSED. SEDZLJ uses measured gross erosion rates from a Sedflume study (McNeil et al., 1996; Jepsen et al., 1997; Roberts et al., 1998) performed at the water body to be modeled to determine the resuspension rates of fine-grained sediment beds and measured erosion rates for sand sized sediments obtained from the literature (Roberts et al., 1998) for noncohesive sediment beds as the basis to compute sediment transport. The incorporation of SEDZLJ into ECOMSED was performed by Dr. Craig Jones (developer of the SEDZLJ computer code) of Sea Engineering, Inc. (SEI). The resulting computer code was peer-reviewed by Dr. Earl Hayter of the USEPA and was applied for the cap erosion analysis of the Lower Passaic River (HydroQual, 2007).

The SED module is configured to run in conjunction with the hydrodynamic model and a wave model (if waves are included). SED uses the same numerical grid, structure and computational framework as the hydrodynamic model. Sediment dynamics inherent in the model includes sediment resuspension, transport and deposition of cohesive and noncohesive sediments. SEDZL modeling framework is discussed in Section 6.2 and SEDZLJ modeling framework is presented in Section 6.3.

6.2 SEDZL Modeling Framework

Cohesive sediments, as referred to herein, represent fine-grained sediments and tailings of particle diameters less than 75 μm (clay-silt range), while noncohesive sediments are coarser particles with diameters between 75 - 500 μm (fine-medium sand range). Coarse sand and gravel, with particle diameters greater than 500 μm, are moved as bed load transport, which is not considered in this model because coarse-grained sediments normally comprise a small fraction of the bed in estuarine and ocean systems. Neglecting bed load will thus have negligible effect on the model results.

Both resuspension and deposition mechanisms depend upon the shear stress induced at the sediment-water interface. Computation of bottom shear stresses is an integral part of the sediment transport processes. The resuspension of sediments from the cohesive bed follows the characteristic equation for resuspension of cohesive sediments, resulting in a certain mass flux of sediments into the water column. Resuspension of sediments from a noncohesive sediment bed, on the other hand, is based on the suspended load theory of van Rijn (1984; 1993). In both cases, the total mass of sediments resuspended into the water column is then apportioned between the fraction of cohesive and noncohesive sediments based on the respective fractions in the bed. Settling of cohesive sediments in the water column is modeled as a function of aggregation (flocculation) and settling. The effect of internal shear rates and water column concentrations on particle aggregation is implicitly defined in the settling velocity formulation. Noncohesive sediments, on the other hand, are assumed to settle discretely, without interaction with other particles. A unique characteristic of the model is its ability to use experimental results to describe parameters in the formulations of resuspension and deposition, including the effects of aggregation of cohesive sediment particles.

Sediments forming a cohesive sediment bed consolidate with time. A vertically segmented bed model incorporates the effect of consolidation on the sediment bed properties. Forcing functions such as time-varying sediment loads from river inflows, and concentrations of solids at open boundaries can be easily specified. Output from SED includes the spatial and temporal distribution of total suspended solids, water column concentrations of cohesive and noncohesive sediments, bed fractions of cohesive and noncohesive sediments, the mass of sediment deposited/eroded, and subsequent change in bed elevations.

6.2.1 Governing Equation

The three-dimensional advection-dispersion equation for transport of sediment of size class k (k =1,2) is:

$$\frac{\partial C_k}{\partial t}+\frac{\partial UC_k}{\partial x}+\frac{\partial VC_k}{\partial y}+\frac{\partial (W-W_{s,k})C_k}{\partial z}$$

$$=\frac{\partial}{\partial x}\left(A_H\frac{\partial C_k}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial C_k}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_H\frac{\partial C_k}{\partial z}\right) \quad (6\text{-}1)$$

Boundary conditions:

$$K_H\frac{\partial C_k}{\partial z}=0,\ z\to\eta \quad (6\text{-}2a)$$

$$K_H \frac{\partial C_k}{\partial z} = E_k - D_k, \; z \to -H \tag{6-2b}$$

where C_k = suspended sediment concentration of size class k (represented by 1 and 2, for cohesive and noncohesive sediments, respectively; u,v,w = velocity in the x, y and z-direction; A_H = horizontal diffusivity; K_H = vertical eddy diffusivity; E_k, D_k = resuspension and deposition flux of size class k; η = water surface elevation above a specified datum; and H = bathymetric depth below the datum. Equation 6-1 is easily transformed to orthogonal curvilinear and sigma coordinates. When so done, it appears similar to Equation (3-55 and 3-56).

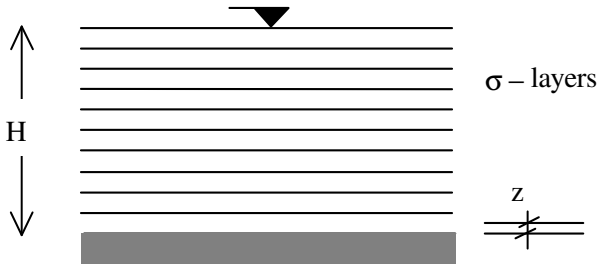
6.2.2 Bottom Shear Stress Computations

The bed shear stress is computed as follows:

$$\tau = \rho u_*^2 \tag{6-3}$$

where ρ = density of the suspending medium; and u_* = shear velocity.

For currents only, the shear velocity is defined by the Prandtl-von Karman logarithmic velocity profile



$$u_* = \frac{k u}{\ln\left(\frac{z}{z_0}\right)} \tag{6-4}$$

where k = von Karman constant $\cong$ 0.40; u = resultant near-bed velocity; z = depth at the center of the bottommost layer; and z_0 = bottom friction specified as input to the model.

For wave-current induced bottom shear stress computations, the reader is referred to Section 7.2.

6.2.3 Resuspension of Cohesive Sediments

Laboratory experiments (Parchure and Mehta, 1985; Tsai and Lick, 1987; Graham et al., 1992) and field studies (Hawley, 1991; Amos et al., 1992) have revealed that only a finite amount of sediment can be resuspended from a cohesive sediment bed exposed to a constant shear stress as a result of armoring. The amount of fine-grained sediment resuspended from a cohesive sediment bed is given by Gailani et al. (1991) as:

$$\varepsilon = \frac{a_0}{T_d^m}\left(\frac{\tau_b - \tau_c}{\tau_c}\right)^n \tag{6-5}$$

where ε= resuspension potential (mg cm^{-2}); a_0= constant depending upon the bed properties; T_d = time after deposition (days); τ_b= bed shear stress (dynes cm^{-2}); τ_c = critical shear stress for erosion (dynes cm^{-2}); and m, n = constants dependent upon the depositional environment.

The parameters in the above equation are generally determined from shaker studies (Tsai and Lick, 1987). Shaker studies have been conducted in at least twelve aquatic systems (Figure 6-1) and the data obtained from those studies have been used in a number of sediment transport modeling efforts (e.g., Ziegler and Nisbet, 1994; Lick et al., 1995; HydroQual, 1998).

Experimental results show that the total amount of sediment flux into the water column is not resuspended instantaneously but over a time period of approximately one hour (Tsai and Lick, 1987; MacIntyre et al., 1990). The resuspension rate is thus given by

$$E_{tot} = \frac{\varepsilon}{3600 \text{ seconds}} \tag{6-6}$$

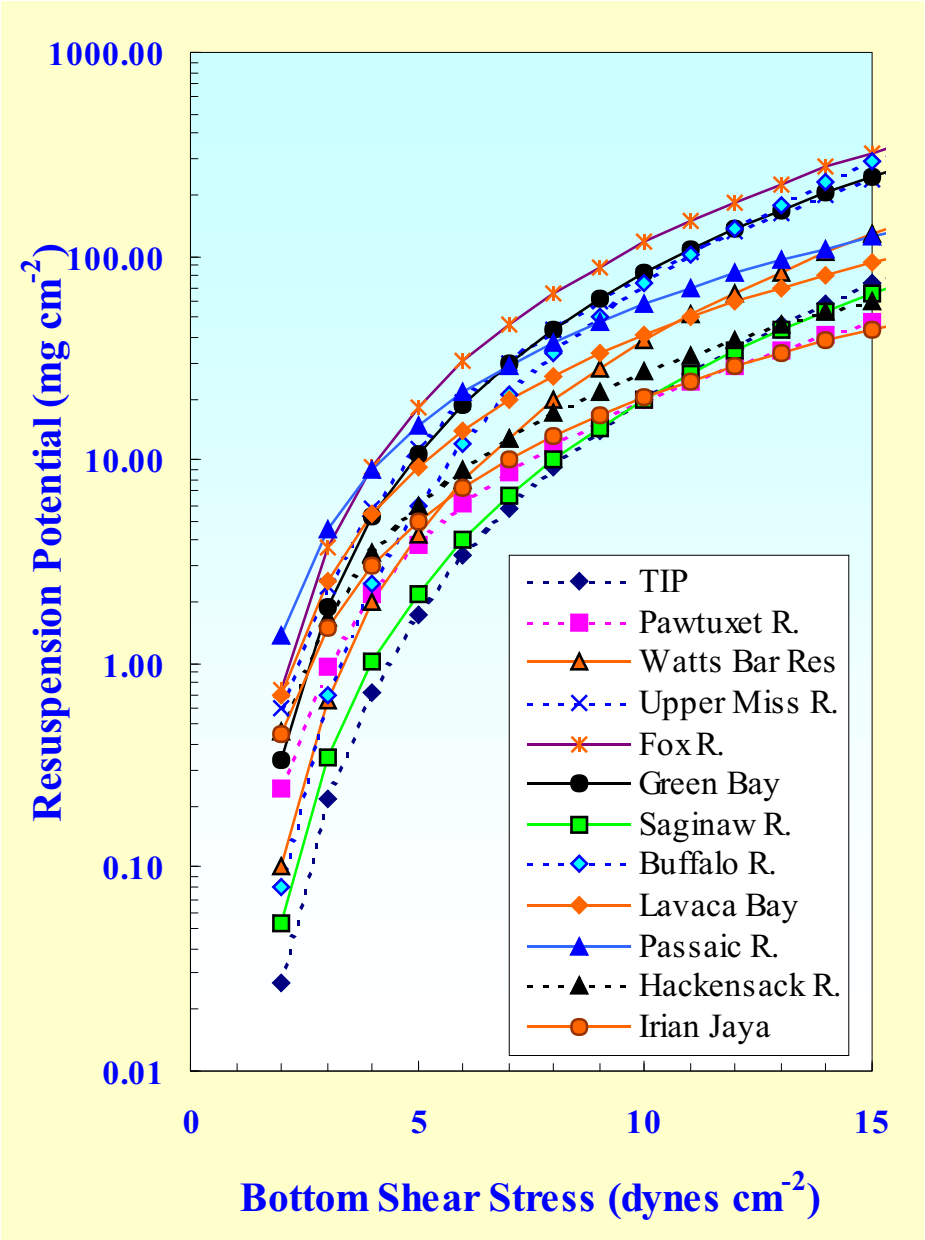
where E_{tot} is assumed to be constant until all available sediment is eroded. Once the amount ε has been resuspended, E_{tot} is set to zero until additional sediment is deposited and available for resuspension or until the shear stress increases (Gailani et al., 1991). The resuspension rate of sediments of class k (E_k), which is needed in the governing equation, is then given by

$$E_k = f_k E_{tot} \tag{6-7}$$

where f_k = fraction of class k sediment in the cohesive bed.

6.2.4 Deposition of Cohesive Sediments

The cohesive nature of particles in suspension causes discrete particles to aggregate, forming flocs that vary in size and settling velocities. Variation in concentration and internal shear stress affects both the size and settling speed of the floc (Burban et al., 1990). Characterization of depositional fluxes in natural water systems can thus be



Resuspension potential as a function of bed shear stress
for twelve different aquatic systems (based on shaker studies).

FIGURE 6-1

difficult. In SED, the deposition rate for cohesive sediments depends directly upon the sediment flux approaching the bed and the probability of the flocs sticking to the bed, according to the formulation of Krone (1962) as follows:

$$D_1 = -W_{s,1} C_1 P_1 \tag{6-8}$$

in which D_1 = depositional flux (g cm^{-2} s^{-1}); $W_{s,1}$ = settling velocity of the cohesive sediment flocs (cm s^{-1}); C_1 = cohesive suspended sediment concentration (g cm^{-3}) near the sediment-water interface; and P_1 = probability of deposition.

Settling speeds of cohesive flocs have been measured over a large range of concentrations and shear stresses (Burban et al., 1990). Experimental results show that the settling speed of cohesive flocs is dependent on the product of concentration and the water column shear stress at which the flocs are formed, resulting in the following relationship:

$$W_{s,1} = \alpha (C_1 G)^{\beta} \tag{6-9}$$

in which $W_{s,1}$, C_1, and G are expressed in m day^{-1}, mg L^{-1}, and dynes cm^{-2}, respectively. The above equation implicitly incorporates the effect of internal shear stress (G) on aggregation and settling. For saltwater suspensions, analysis of Burban et al. (1990) data revealed values of α and β of 2.42 and 0.22, respectively. Figure 6-2 shows a comparison of Equation 6-9 using the above parametric values and Burban et al. data.

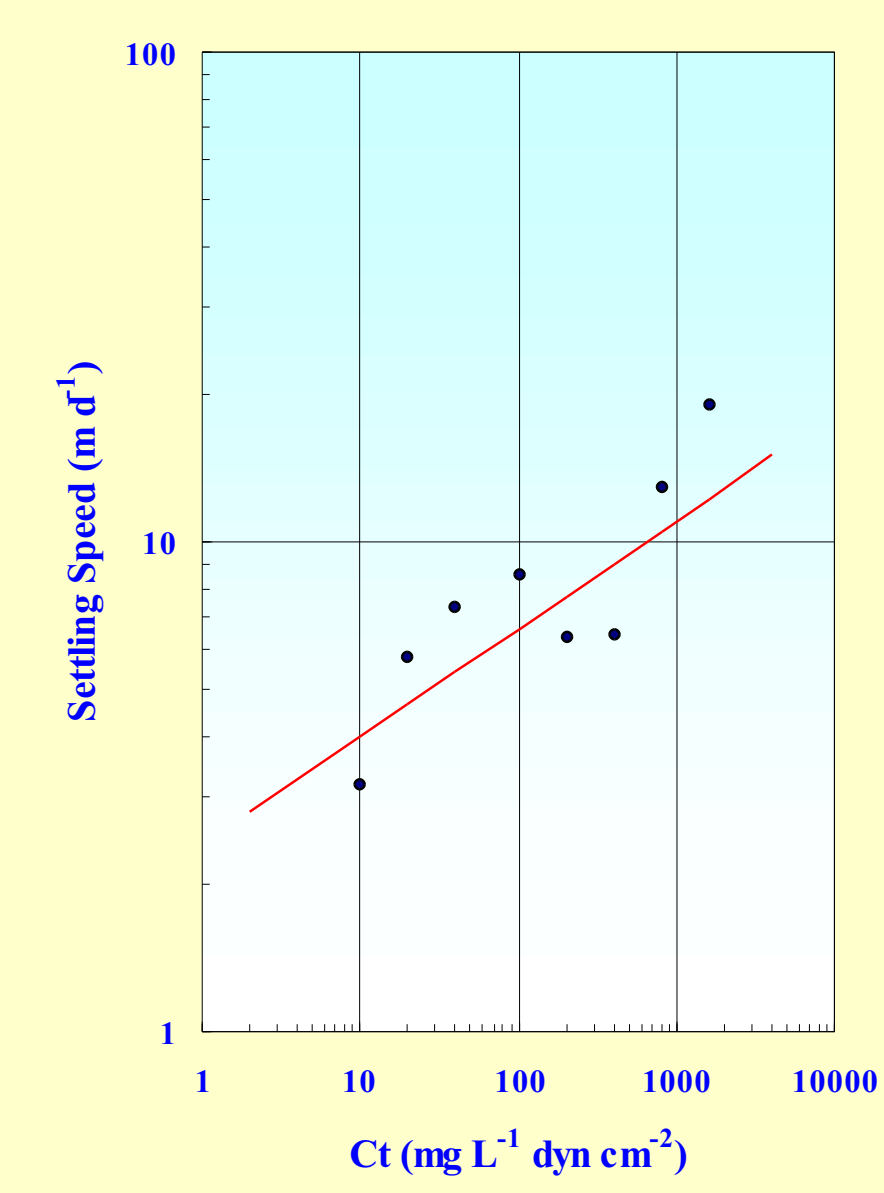
The water column shear stress (G) is computed from the hydrodynamic output (i.e., current velocity and vertical eddy viscosity) as follows:

$$G = \rho K_M \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right]^{1/2} \tag{6-10}$$

where K_M = vertical eddy viscosity, and ρ = density of the suspending medium.

The probability of deposition (P_1) parameterizes the effects of floc size heterogeneity and near-bed turbulence on the deposition rate. The complex interactions occurring at the vicinity of the sediment-water interface cause only a certain fraction of settling sediments to actually become incorporated into the bed (Krone, 1962; Partheniades, 1992). Krone (1962) was the first to develop a relationship for the probability of deposition

$$P_1 = \begin{cases} 1 - \dfrac{\tau_b}{\tau_d}, & \tau_b \le \tau_d \\ 0, & \tau_b > \tau_d \end{cases} \tag{6-11}$$



Settling speed function for cohesive sediments settling in saltwater compared to mean values of Burban et al., (1990) data.

FIGURE 6-2

where τ_b = bottom shear stress (dynes cm^{-2}), and τ_d = critical shear stress for deposition (dynes cm^{-2}). The above formulation has been incorporated into several cohesive sediment transport models including: STUDH (Ariathurai and Krone, 1976); TSEDH (Shrestha and Orlob, 1994); CSTM-H (Hayter and Mehta, 1986); and SEDZL (Ziegler and Nisbet, 1996). The critical shear stress for deposition (τ_d) is typically used as a calibration parameter in modeling studies because it is not well known. Limited experimental data indicate τ_d ranges between 0.6 and 1.1 dynes cm^{-2}, depending upon sediment concentration and type (Krone, 1962; Mehta and Partheniades, 1975). Partheniades (1992) developed an empirically based formulation that realistically represents the effects of variable floc size on probability of deposition. This can be expressed as:

$$P_1 = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y} e^{-\frac{\omega^2}{2}} d\omega \tag{6-12}$$

where ω = dummy variable, and

$$Y = 2.04 \log \left[0.25 \left(\frac{\tau_b}{\tau_{b,min}} - 1 \right) e^{1.27 \tau_{b,min}} \right] \tag{6-13}$$

where $\tau_{b,min}$ = bottom shear stress below which $P_1 = 1$ (dynes cm^{-2}).

The probability integral in Equation (6-12) can be accurately approximated by a cubic equation, yielding (for $0 \le Y < \infty$).

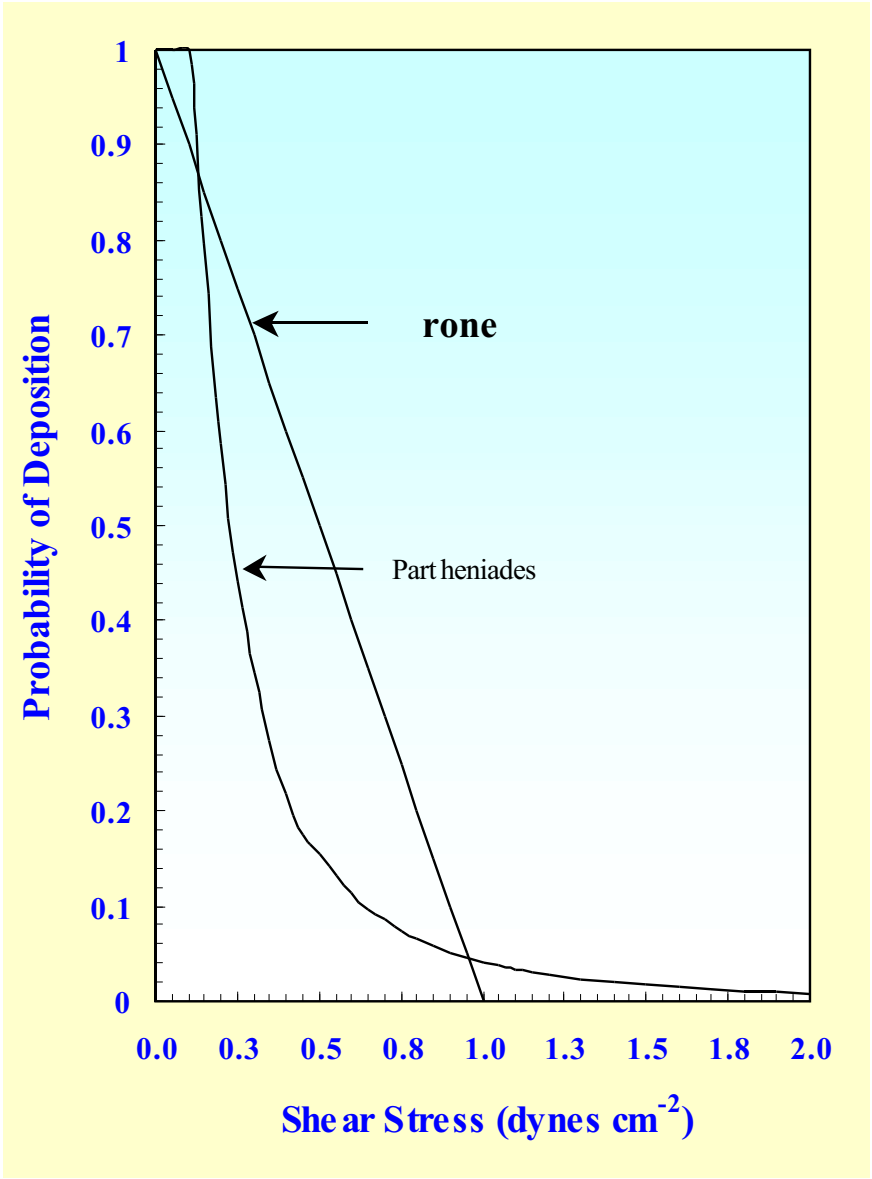
$$P_1 = \frac{1}{\sqrt{2\pi}} e^{-\frac{Y^2}{2}} \left(0.4362z - 0.1202z^2 + 0.9373z^3 \right) \tag{6-14}$$

where:

$$z = (1 + 0.3327Y)^{-1} \tag{6-15}$$

for $Y < 0, P_1(-Y) = 1 - P_1(Y)$

There are two primary differences between the Krone and Partheniades probability of deposition formulations as shown in Figure 6-3. First, the Partheniades approach results in significantly higher deposition than Krone's method in the low shear stress region, with $P_1 = 1$ for shear stresses up $\tau_{b,min}$. Secondly, Partheniades' formulation allows finite deposition to occur, even for higher shear stresses.



Comparison of Krone (1962) and Parpheniades (1992) formulations for the probabilities of deposition of cohesive sediments.

FIGURE 6-3

6.2.5 Cohesive Sediment Bed Model

To realistically simulate the effects of sequential deposition and erosion, and the subsequent change in bed properties such as thickness and erodibility characteristics, a vertically segmented model of the cohesive sediment bed is constructed as shown in Figure 6-4. This is achieved by discretizing the sediment bed into seven layers. Each layer of the bed is characterized by a dry density (ρ_d), a critical shear stress for erosion (τ_{cr}), and an initial thickness. The "time after deposition" for each layer increases linearly from one day at the surface, which is composed of freshly deposited material, to seven days in the bottom layer. Previous laboratory results (Tsai and Lick, 1987; MacIntyre et al., 1990) have indicated that consolidation effects on resuspension are minimal after seven days of deposition, hence deposited sediments aged seven days or more are assumed to be seven days old. The resuspension potential equation shows that each layer decreases with time of consolidation (T_d), in accordance with the $(T_d)^{-m}$ term. The layered bed model conserves mass, with resuspension and deposition fluxes occurring only at the bed level. During the course of a simulation, the bed model accounts for changes in thickness, the mass of cohesive and noncohesive sediments in each layer, resulting from resuspension and deposition at the sediment-water interface.

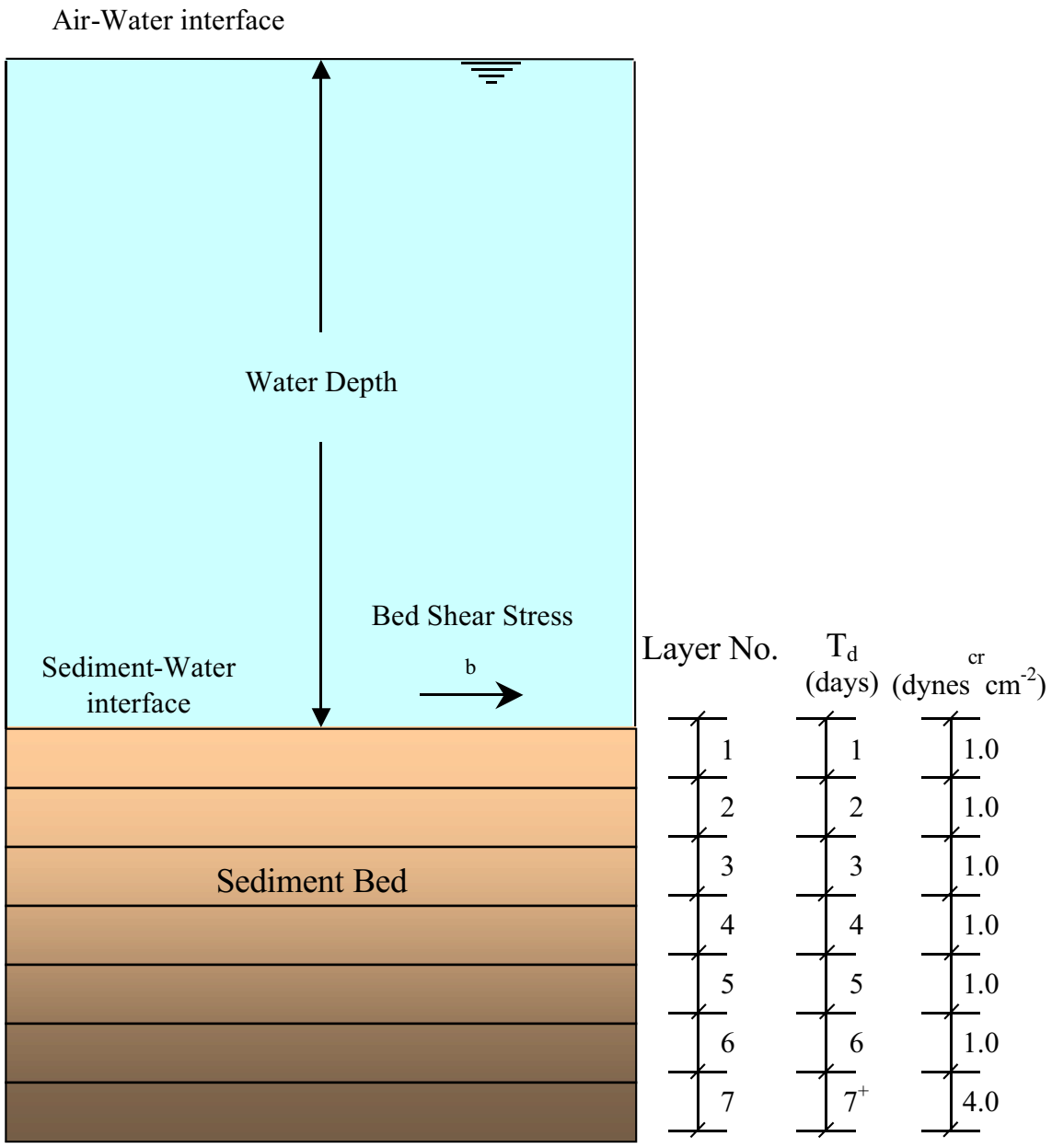
6.2.6 Resuspension of Noncohesive Sediments

The resuspension of sediment from a non-cohesive sediment bed is calculated using a procedure developed by van Rijn (1984). The van Rijn method has been shown to yield good results for predicting suspended load of fine sands (van Rijn, 1984; Garcia and Parker, 1991; van Rijn et al., 1993; Ziegler and Nisbet, 1994). Only a brief overview of the van Rijn method will be presented here, for details of the calculation procedure see van Rijn (1984). The first step in the procedure is to compare the bed-shear velocity u_* with the critical bed-shear velocity, $u_{*,crbed}$ based on the local D_{50}, according to Shields criterion for initiation of motion. Suspended transport will only occur if the bed-shear velocity exceeds both the Shields criterion for bed load movement and the critical bed-shear velocity for suspension, $u_{*,crs}$. If resuspension does occur, the local D_{50} and bed-shear velocity, u_*, are used to determine the reference concentration at a height of z = a above the sediment bed, C_a. Finally, the local values of u_*, D_{50} and C_a are used to calculate the suspended load transport rate.

Using the van Rijn method, the following procedure is adopted to calculate the suspended load transport.

1. Compute the critical bed shear velocity for initiation of motion

A non-dimensional particle parameter is first introduced:



Schematic of the sediment bed model.

FIGURE 6-4

$$D_* = \left[\frac{(s-1)g}{\upsilon^2}\right]^{1/3} D_{50} \tag{6-16}$$

where s = specific gravity of the particles; g = gravitational acceleration; υ = kinematic viscosity; and D_{50} = median particle diameter in the bed.

The critical bed shear velocity for initiation of bed motion is then computed using the Shields criteria as

$$u_{*,crbed} = \left[(s-1)gD_{50}\theta_{cr}\right]^{1/2} \tag{6-17}$$

where θ_{cr} = critical mobility parameter which is defined as

$$\begin{aligned}
&\theta_{cr}=0.24\ D_*^{-1} && D_* \le 4\\
&\theta_{cr}=0.14\ D_*^{-0.64} && 40 < D_* \le 10\\
&\theta_{cr}=0.04\ D_*^{-0.10} && 10 < D_* \le 20\\
&\theta_{cr}=0.013\ D_*^{-0.29} && 20 < D_* \le 150\\
&\theta_{cr}=0.055 && D_* > 150
\end{aligned} \tag{6-18}$$

2. Compute the critical shear velocity for resuspension

The critical shear velocity for resuspension is given by

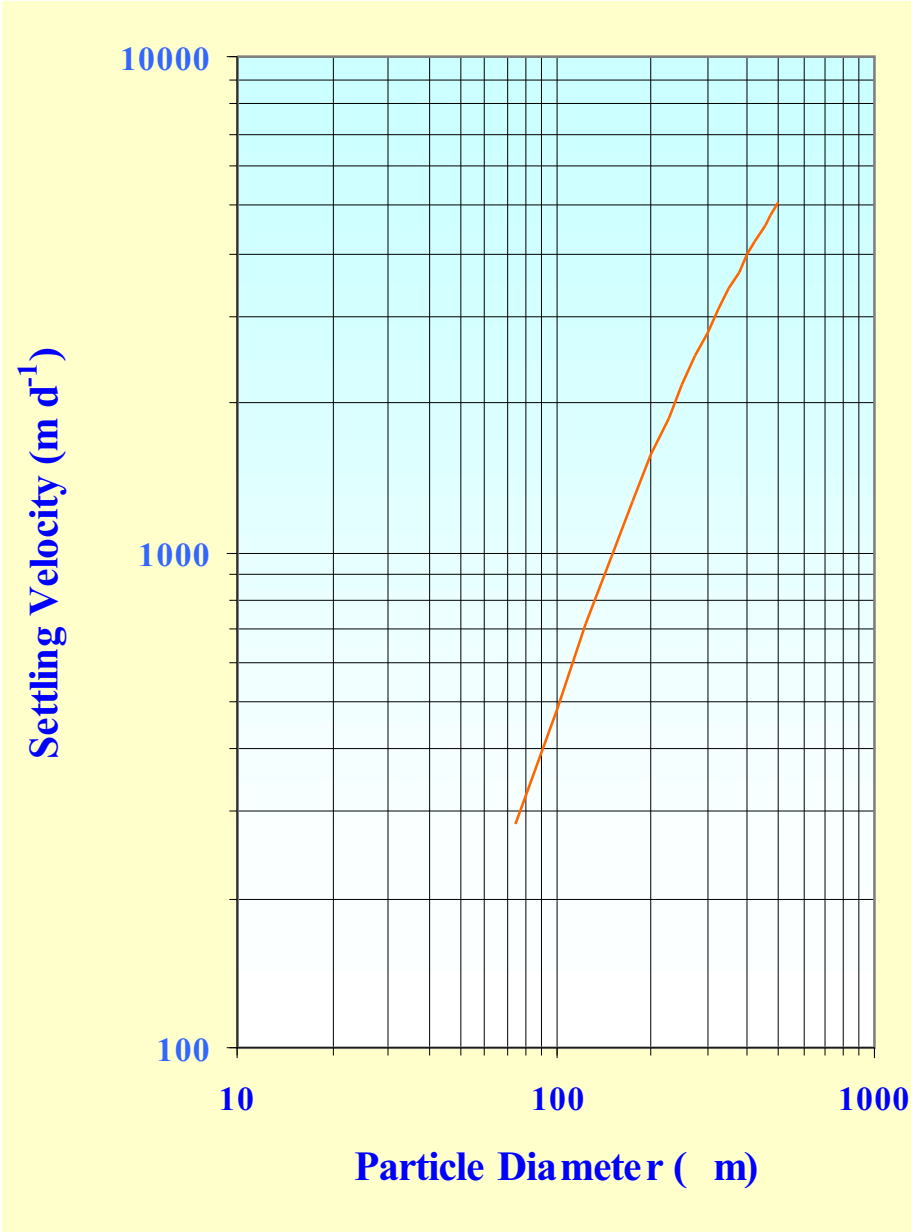
$$u_{*,crsus} = W_{s,2} \tag{6-19}$$

where $W_{s,2}$ = settling velocity of the noncohesive suspended sediment. The settling velocity is specified as input to the model and is computed from the effective particle diameter (D_k) of the suspended sediment using the formulation of Cheng (1997).

$$W_{s,2} = \frac{\upsilon}{D_k}\left[\left(25+1.2D_*^2\right)^{0.5} - 5\right]^{1.5} \tag{6-20}$$

where D_* = non-dimensional particle parameter as shown in Eq.(6-16) with effective particle diameter D_k.

The dependence of $W_{s,2}$ on D_k is illustrated in Figure 6-5, which shows that the settling speeds of suspended sand particles (i.e., $75<D_k<500\mu m$) range from about 3,300 – 59,000 μms^{-1} (i.e., ~ 280 to 5,000 md^{-1}).



Settling velocity as a function of particle diameter for noncohesive sediments (based on Cheng, 1997 formulation).

FIGURE 6-5

3. Compute the bed shear velocity

The near-bed shear velocity due to the flow is computed as in Eq. (6-4).

$$u_* = \frac{k\,u}{\ln\left(\frac{z}{z_0}\right)} \tag{6-21}$$

4. Suspended Load Transport

If the bed shear velocity (u_*) is less than the threshold for motion ($u_{*,crbed}$) or less than the critical shear velocity for resuspension, then deposition occurs . If u_* exceeds $u_{*,crbed}$ and $u_{*,crsus}$, the sediment flux is from the bed to the lower layer of the water column. The suspended load transport is then computed as follows:

Compute the transport stage parameter

$$T = \frac{u_*^2}{u_{*,crbed}^2} - 1 \tag{6-22}$$

Compute the reference level above bed

$$a = \max\,(\,0.01h,\, k_s) \tag{6-23}$$

where h = water depth, and k_s = Nikuradse roughness height.

$$C_a = \frac{0.015 D_k T^{1.5}}{a D_*^{0.3}} \tag{6-24}$$

where Ca is the reference concentration

Compute the β-factor

$$\beta = 1 + 2\left(\frac{W_s}{u_*}\right)^2 \text{ for } 0.1 < \frac{W_s}{u_*} < 1 \tag{6-25}$$

Compute the ϕ-factor

$$\phi = 2.5\left(\frac{W_s}{u_*}\right)^{0.8}\left(\frac{C_a}{C_0}\right)^{0.4} \text{ for } 0.01 < \frac{W_s}{u_*} \le 1 \tag{6-26}$$

where C_o = maximum volumetric bed concentration = 0.65.

Compute the suspension parameter

$$Z' = Z + \phi = \frac{W_s}{\beta k u_*} + \phi \tag{6-27}$$

Compute the F-factor

$$F = \frac{\left(\frac{a}{h}\right)^{Z'} - \left(\frac{a}{h}\right)^{1.2}}{\left(1 - \frac{a}{h}\right)^{Z'}(1.2 - Z')} \tag{6-28}$$

Compute the suspended load transport

$$q_s = F\, z\, u\, C_a \tag{6-29}$$

where z = depth of the lowest σ-layer

Compute resuspension flux from the bed

The resuspension flux is calculated as the difference between the total suspended load transport (or the carrying capacity of the flow) and the existing horizontal sediment flux in the lowest σ-layer. If this difference is greater than zero, erosion occurs, whereas if the difference is less than zero, deposition occurs. It is therefore possible to have deposition even if u_* exceeds $u_{*,crbed}$ and $u_{*,crsus}$.

In the model, resuspension is computed as

$$E = \frac{(\rho_s q_s - qzC_z)\Delta t}{\Delta x \Delta y} \tag{6-30}$$

where C_z = concentration of suspended sediment in the lowest σ layer; ρ_s is sediment particle density; Δt = time step; and $\Delta x\, \Delta y$ = surface area of bottom.

6.2.7 Deposition of Noncohesive Sediments

When the bed shear velocity (u_*) is less than the critical value ($u_{*,crbed}$ or $u_{*,crsus}$), then the sediments in the water column deposit to the bed according to the formula:

$$D_2 = W_{s,2} C_2 \tag{6-31}$$

where D_2 = noncohesive sediment depositional flux; $W_{S,2}$ = settling velocity; and C_2 = near-bed suspended sediment concentration.

6.2.8 Noncohesive Sediment Bed Armoring

An important assumption in the van Rijn procedure is that the bed sediments are homogeneous. A non-cohesive sediment bed is generally comprised of a wide range of particle sizes, from fine sands that are suspendable to coarse sands and gravels that are only transported as bed load. Bed armoring occurs when fine sands are eroded from a heterogeneous sediment bed and the coarser material that cannot be resuspended remains on the bed surface. During erosion, the suspendable sediments in the near-surface layer (referred to as the active layer) are depleted and a layer of coarse, non-suspendable sediments forms. Continuous depletion of suspendable sediments in the active layer will eventually reduce the erosion rate to zero, at which point the active layer is composed entirely of non-suspendable sediments, i.e., coarse sand and gravel. The sediment bed then becomes armored (Shen and Lu, 1983; Karim and Holly, 1986; van Niekerk et al., 1992).

The bed armoring process can be modeled by assuming that the sediment bed is composed of an active layer, which interacts with the water column, and a parent bed layer, which is below the active layer (Karim and Holly, 1986; van Niekerk et al., 1992). Resuspension of bed sediments is assumed to occur only from the active layer such that

$$E_2 = f_a E \tag{6-32}$$

where f_a = fraction of sediment in the active layer that is resuspendable; and E = resuspension rate for a homogeneous bed calculated using the van Rijn method. The fraction of resuspendable sediment in the parent bed (f_p) is determined from the initial grain size distribution data. The active layer thickness is determined using a modified form of the equation proposed by van Niekerk et al., (1992).

$$T_a = \frac{D_{50}\tau}{5\tau_{c50}} \tag{6-33}$$

where τ = bed shear stress; and τ_{c50} = critical shear stress necessary to initiate bed load motion for sediment with bed D_{50} and is calculated using Shields criteria. Changes in the composition of the active layer are made following the method of Karim and Holly (1986).

6.3 SEDZLJ Modeling Framework

The integration of SEDZLJ sediment transport routines into ECOMSED and other related code modifications provided four primary benefits to ECOMSED:

1. Computation of erosion fluxes as a function of measured erosion rates,
2. Division of total erosion fluxes into bedload and suspended load components,
3. Simulation of bedload transport, and
4. Simulation of a user-defined number of particle size classes.

These code modifications substantially improve the ability of ECOMSED to simulate the expected differential transport of sediments comprised of particles with a continuum of grain sizes and subject to significant bedload transport.

6.3.1 Erosion

The governing equations for erosion in SEDZLJ (Jones and Lick, 2001) are:

$$E\left(\tau^b\right)=\left(\frac{\tau_{m+1}-\tau^b}{\tau_{m+1}-\tau_m}\right)E_m+\left(\frac{\tau^b-\tau_m}{\tau_{m+1}-\tau_m}\right)E_{m+1} \tag{6-34}$$

$$\ln E\left(T\right)=\left(\frac{T_0-T}{T_0}\right)\ln E^{L+1}+\left(\frac{T}{T_0}\right)\ln E^{L} \tag{6-35}$$

where: $E(\tau^b)$ = erosion rate as a function of shear stress (τ); τ^b = bottom shear stress; τ_m = critical resuspension shear stress less than τ^b; τ_{m+1} = critical resuspension shear stress greater than τ^b; $E(T)$ = erosion rate as a function of depth in the sediment bed; T = sediment layer thickness; T_0 = initial sediment layer thickness; and the superscripts L and $L+1$ denote depths in the sediment profile at the upper and low limits of the eroding sediment layer. Equations 6-34 and 6-35 can be combined to express the erosion rate as a function of both shear stress and depth. The onset of erosion is identified as the critical shear stress for erosion, τ_{ce}, and is defined as the shear stress at which erosion is initiated at a rate of 10^{-4} cm/s.

For non-cohesive particles, the critical shear stress for erosion can be estimated from the particle diameter as:

$$\tau_{ce} = \begin{cases} d & for\ d \le 400\,\mu m \\ \\ 4.14d & for\ d > 400\,\mu m \end{cases} \tag{6-36}$$

6.3.2 Non-Cohesive Bedload vs. Suspended Load Fractionation

When the shear stress acting on grains comprising the bed exceeds the critical shear stress for a given grain size, particles may be transported as bedload (in a thin layer in contact with the bed) or as suspended load (fully entrained in the water column away from the bed). The governing equations used to fractionate eroded sediments into bedload and suspended load are:

$$f_{SL} = \begin{cases} 0 & for\ \tau^b \le \tau_{ce} \\ \dfrac{\ln\left(u_*/w_s\right) - \ln\left(\sqrt{\tau_{cs}/\rho_w}/w_s\right)}{\ln(4) - \ln\left(\sqrt{\tau_{cs}/\rho_w}/w_s\right)} & for\ \tau^b > \tau_{cs}\ and\ \dfrac{u*}{w_s} < 4 \\ 1 & for\ \dfrac{u_*}{w_s} > 4 \end{cases} \tag{6-37}$$

$$\tau_{cs} = \begin{cases} \dfrac{1}{\rho_w}\left(\dfrac{4w_s}{d_*}\right)^2 & for\ d \le 400\,\mu m \\ \\ \dfrac{1}{\rho_w}\left(4w_s\right)^2 & for\ d > 400\,\mu m \end{cases} \tag{6-38}$$

where: τ_{cs} = critical shear stress for transport as suspended load; w_s = particle fall velocity; d_* = particle dimensionless diameter = $d\left[\left(\rho_s - 1\right) g/\nu^2\right]$; d = particle diameter; ρ_s = particle density; f_{SL} = fraction of the total amount eroded that is transported as suspended load; and u_* = shear velocity. The fraction transported as bedload = (1-f_{SL}). Equations 6-37 and 6-38 can be used in

conjunction with the particle grain size distribution and critical shear stress for erosion to express the erosion flux of sediment by grain size that is transported by bedload and suspended load as a function of the bottom shear stress.

The bottom shear stress acting on the bed (*i.e.* the total bed shear stress) is a function of the total hydrodynamic roughness and can be expressed in terms of two separate components: (1) form roughness; and (2) grain roughness (*i.e.* skin friction). Individual grains on the surface of the sediment bed are subjected only to the skin friction component of the total bed shear stress. The total bed shear stress is computed from the near-bed hydrodynamic velocities according to the "log law" velocity profile:

$$u(z_b) = \frac{u_{*T}}{\kappa} \ln\left(\frac{z_b}{z_0}\right) \tag{6-39}$$

$$\tau_T = \rho\, u_{*T}{}^2 = \rho\, C_d\, u(z_b)^2 \tag{6-40}$$

$$C_d = \left(\frac{\kappa}{\ln \frac{z_b}{z_0}}\right)^2 \tag{6-41}$$

where: $u(z_b)$ = near-bed flow velocity, u_{*T} = near-bed shear (friction) velocity; κ = von Karman constant = 0.4, z_b = height of the near-bed layer above the bed surface; and z_0 = bed roughness height; τ_T = total bed shear stress; ρ = density of the fluid; and C_d = coefficient of drag. In the sigma layer coordinate system of the hydrodynamic model, z_b is height above the bed at the mid-point of the bottom sigma layer.

The shear stress component associated with skin friction can be computed as a function of the total bed shear stress as follows (Grant and Madsen, 1982; Glenn and Grant, 1987):

$$u_{*S} = u_{*T}\left(\frac{\ln\frac{z_b}{z_0}}{\ln\frac{z_b}{z_{0S}}}\right) \tag{6-42}$$

$$\tau_S = \rho\, u_{*S}^{\,2} \tag{6-43}$$

where: u_{*S} = the near-bed shear velocity attributable to skin friction; and z_{OS}= the roughness height of particles comprising the bed surface; τ_S = the skin friction shear stress.

As part of the model development process, SEI and HydroQual verified that the SEDZLJ code was properly implemented in ECOMSED by simulating and successfully reproducing the laboratory results of Little and Mayer (1972).

6.3.3 Bed Consolidation

Sanford's (2007) paper outlines in detail the overall theory behind the consolidation model implemented here. Essentially as cohesive sediments deposit or erode the density of the sediment bed changes in response to the addition or reduction of overlying sediment. The consolidation model reproduces the measured effects of changes in sediment bed properties at any point in the sediments as a function of overlying bed mass. Sanford (2007) also generally included the effects of bioturbation which is not implemented in this version of ECOMSED.

The basic premise of Sanford's model was to reproduce the changes in solids volume concentration (ϕ_s) and critical shear stress for erosion (τ_c) at a point due to changes in sediment bed structure. The parameter of interest (ϕ_s or τ_c) is defined by an equilibrium profile which is generally described by the equation:

$$\phi_s = \phi_\infty - (\phi_\infty - \phi_{s0})\exp(-cm) \tag{6-44}$$

where ϕ_∞ is the ultimate equilibrium value, ϕ_{s0} is the surface value, m is the mass of the overlying sediment bed (can be converted to z with a density profile), and c is an empirically determined coefficient. The equilibrium profile is defined relative to the instantaneous sediment/water interface, so it moves with changes in the sediment bed height.

Once a sediment specific equilibrium profile has been determined, this can be applied to deposited layers in the sediment bed. At any point in time (t) and bed mass position (m), the instantaneous value of the property of interest is assumed to approach equilibrium in a first order manner.

$$\frac{\partial \phi_s}{\partial t} = r_c \left(\phi_{seq} - \phi_s\right) H\left(\phi_{seq} - \phi_s\right) - r_s \left(\phi_s - \phi_{seq}\right) H\left(\phi_s - \phi_{seq}\right) \quad (6\text{-}45)$$

where H is the Heaviside step function (H=1 when the argument is ≥0 and H=0 otherwise), r_c (1/day) is the empirically determined first order consolidation rate and r_s (1/day) is the empirically determined first order swelling rate.

The model structure above is mechanistically applied in SEDZLJ to deposited sediments. Sediments below a deposited layer, the parent bed, are assumed to retain field measured properties and not change. The consolidation model as implemented in SEDZLJ models the equilibrium profile of bulk density (ρ_b, g/cm^3) instead of ϕ_s. Since ρ_b varies as a linear function of ϕ_s, the overall mechanistic description remains unchanged. The reason for this change is because SEDZLJ is based on Sedflume measured erosion rates. Sedflume measured erosion rates (E) in consolidation experiments (Roberts et al., 1998) have been most accurately described with a power law formulation that is a function of applied shear stress (τ) and bulk density.

$$E = A\tau^n \rho_b{}^m \quad (6\text{-}46)$$

where A, n, and m are empirically determined coefficients. Additionally, an erosion rate threshold of 0.0001 cm/s is used in Sedflume to define the critical shear stress; therefore, it is a simple exercise to calculate critical shear stress for erosion (τ_c) using the above equation with empirically determined coefficients and the known erosion rate.

$$\tau_c = \sqrt[n]{\frac{0.0001}{A\rho_b{}^m}} \quad (6\text{-}47)$$

With this information, the prediction of bulk density using the equilibrium profile and first order differential equation, the critical shear stress and erosion rate for any layer in the deposited sediments is easily calculated.

The above description is used for deposited beds in the cohesive size ranges. Sandy beds may also deposit. The bulk density of sands is assumed constant in the model at a value defined by the user. The mass of a sandy layer is still used mechanistically in Eq. 6-45 to determine the equilibrium density of layers below the sand, since the greater weight of the sandy layer will result in a higher degree of consolidation. The erosion properties of a deposited sandy layer are determined in an algorithm equivalent to the erosion properties of the sandy active layer in the SEDZLJ model [i.e. values are determined from Roberts et al., (1998) quartz data].

The following subroutines have been added for SEDZLJ with consolidation:

- SJ_SHUFFLE – Incorporates a sub-grid into the SEDZLJ model to handle the consolidation of deposited material.
- SJ_CONSOL – Calculates equilibrium bulk density profile, the current bulk density for each sub-grid layer, and the resulting critical shear stress for that layer.

7.0 Wave Module

7.1 Introduction

Prediction of the wave dynamics is based on a parametric type wave model developed for this study in an orthogonal curvilinear coordinate system. The model is based on a Great Lakes Environmental Research Laboratory (GLERL) wave model developed by Donelan (1977) and modified by Schwab et al. (1984). This is a parametric type model based on the conservation of momentum applied to deep water waves (ratio of water depth to wave length greater than 0.5). The governing equations describe the local momentum balance rather than the transport of energy. The momentum input to the model results from drag on the waves, which depends on the wave height and the differential speeds between the wave and the wind. An important feature of this model is the provision for a "fossil" wave field that may be left behind by a rapidly changing wind (Schwab et al., 1984). The model determines its computational time step dynamically based on the maximum winds for each hour. Given a description of the coastal bathymetry and a two dimensional, time-dependent wind field, the model predicts significant wave heights, wave periods, and wave directions.

The original GLERL model has successfully been applied to Lake Michigan (Liu et al., 1984) and Lake Erie (Schwab et al., 1984). It is also being used in the Great Lakes Coast Watch program. Additional application of the model in an estuarine environment includes the study on the prediction of waves in Chesapeake Bay (Lin et al. 1999). The model has also been compared against four currently available and well-recognized wave models (ACES, HISWA, WAVD and SWAN described by Leenknecht et al. (1992), Booij and Holthuijsen (1995), Resio and Perrie (1989) and Holthuijsen et al. (1993), respectively. The GLERL model performed quite well in simulating the wave field generated by tropical storm Danielle over northern Chesapeake Bay in September 1992. It gave the best prediction of significant wave height and showed a good response to a sharply turning wind.

The current wave model differs from the original GLERL model in two ways. First, the wave model is transformed to a curvilinear coordinate system to take advantage of the orthogonal curvilinear grid of the ECOM hydrodynamic model used in the present study. Second, it incorporates the frictional effect on the wave as it moves into shallower water.

The formulation of the wave prediction model is based on the assumption that the potential and kinetic energies are equally partitioned and that the deep water linear wave theory applies such that the group velocity is one half the phase speed. The transformation of the wave momentum equation into an orthogonal curvilinear coordinate system (ξ_1, ξ_2, z) as shown in Figure 7-1, yields the following momentum conservation equations:

$$\frac{\partial M_{\xi_1}}{\partial t} + \frac{1}{h_1 h_2}\left[\frac{\partial\left(h_2 T_{\xi_1\xi_1}\right)}{\partial \xi_1} + \frac{\partial (h_1 T_{\xi_1\xi_2})}{\partial \xi_2}\right] = \frac{\tau^w_{\xi_1}}{\rho_w} \tag{7-1}$$

$$\frac{\partial M_{\xi_2}}{\partial t}+\frac{1}{h_1 h_2}\left[\frac{\partial (h_2 T_{\xi_1\xi_2})}{\partial \xi_1}+\frac{\partial (h_1 T_{\xi_2\xi_2})}{\partial \xi_2}\right]=\frac{\tau^w_{\xi_2}}{\rho_w} \tag{7-2}$$

The momentum components M_{ξ_1} and M_{ξ_2} are defined as

$$M_{\xi 1} = g\int_o^\infty \int_o^{2\pi} \frac{F(f,\theta)}{C(f)} \cos\theta \, d\theta \, df \tag{7-3}$$

and

$$M_{\xi 2} = g\int_o^\infty \int_o^{2\pi} \frac{F(f,\theta)}{C(f)} \sin\theta \, d\theta \, df \tag{7-4}$$

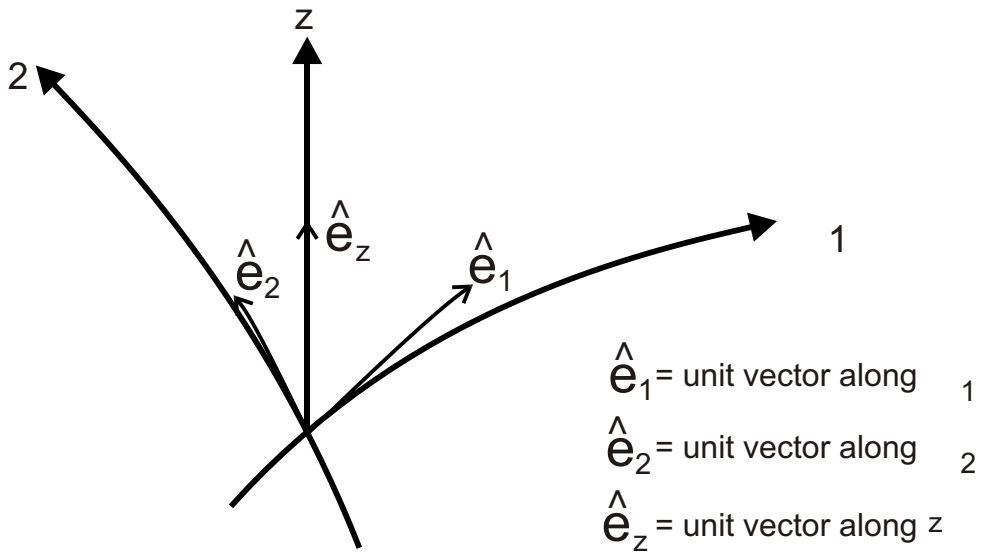
Here $F(f, \theta)$ is the wave energy spectrum as a function of frequency (f) and direction (θ) and $C(f)$ is the phase speed. τ_{ξ_1} and τ_{ξ_2} are wind stress along ξ_1 and ξ_2 directions, ρ_w is the density of air.

The wave momentum flux $T_{\xi_1\xi_1}$, $T_{\xi_1\xi_2}$, and $T_{\xi_2\xi_2}$, are defined as follows:

$$T_{\xi_1\xi_1} = \frac{g}{2}\int_o^\infty \int_o^{2\pi} F(f,\theta)\cos^2\theta \; d\theta \; df \tag{7-5}$$

$$T_{\xi_1\xi_2} = T_{\xi_2\xi_1} = \frac{g}{2}\int_o^\infty \int_o^{2\pi} F(f,\theta)\sin\theta\cos\theta d\theta \, df \tag{7-6}$$

$$T_{\xi_2\xi_2} = \frac{g}{2}\int_o^\infty \int_o^{2\pi} F(f,\theta)\sin^2\theta d\theta df \tag{7-7}$$



Curvilinear coordinate system.

FIGURE 7-1

Considering the wave energy is distributed about the mean angle θ_0 as cosine square and there is no energy for $|\theta-\theta_0|>\pi/2$,

$$F(f,\theta)=\frac{2}{\Pi}E(f)\cos^2(\theta-\theta_o) \tag{7-8}$$

Here E(f) is the spectral wave energy.

If θ_0 is independent of frequency, the momentum fluxes may be expressed in terms of θ_0 and the variance as:

$$\sigma^2=\int_o^\infty E(f)\,df \tag{7-9}$$

Integration of Equations 7-5 to 7-7 results

$$T_{\xi_1\xi_1}=g\left(\frac{\sigma^2}{4}\cos^2\theta_0+\frac{\sigma^2}{8}\right) \tag{7-10}$$

$$T_{\xi_1\xi_2}=T_{\xi_2\xi_1}=g\left(\frac{\sigma^2}{4}\cos\theta_0\sin\theta_0\right) \tag{7-11}$$

$$T_{\xi_2\xi_2}=\left(g\frac{\sigma^2}{4}\sin\theta_0+\frac{\sigma^2}{8}\right) \tag{7-12}$$

It is interesting to note here that Equations 7-10 to 7-12 expressing the momentum flux are independent of the spectral shape. Moreover, $\sigma^2/8$ in Equations 7-10 and 7-12 represents an isotropic term, which causes a wave pressure gradient from areas of high waves toward areas of low waves.

The relation between the variance σ^2 and the momentum components in Equations 7-1 and 7-2 can be obtained by fitting all fetch-limited frequency spectra to JONSWAP function (Hasselmann et al., 1975):

$$E(f)=\alpha g^2(2\Pi)^{-4}f^{-5}\exp\left\{-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right\}\cdot\left\{3.3^{\exp\left[-\frac{(f-f_p)^2}{2\beta^2 f_p{}^2}\right]}\right\} \tag{7-13}$$

$\beta = 0.07$, for $f \le f_p$
$\beta = 0.09$, for $f > f_p$

Two scale parameters f_p and α are peak frequency and the Phillips constant respectively. Donelan (1977) suggested an empirical relation between these two parameters which successfully eliminates the dependency on the fetch length described in the original JONSWAP formula. This relations is as follows:

$$\alpha = 0.0097\left(\frac{U}{C_p}\right)^{2/3} \tag{7-14}$$

Here $C_p = g/2\pi f_p$ and U is wind speed 10 m above sea level.

Integrating equation 7-13 and 7-14 yields

$$\frac{\sigma^2}{|M|} = \frac{C_p}{g} \tag{7-15}$$

and

$$\sigma^2 = 0\cdot 30\alpha g^2 (2\pi)^{-4} f_p^{-4} \tag{7-16}$$

Here $|M|$ is the magnitude of momentum vectors M_{ξ_1} and M_{ξ_2}.

Now the numerical solution is sought to solve equations 7-1, 7-2 (substituting equation 7-10 to 7-12) for variance (σ^2), wave period ($T = \frac{2\pi}{f_p}$) and direction θ. The significant wave height, H_s, is then computed using the following relation.

$$H_s = 4\sigma \tag{7-17}$$

7.2 Wave Induced Bottom Shear Stress

Bed shear stresses due to currents and waves are crucial for calculating sediment resuspension and deposition fluxes (Fredsoe and Deigaard, 1991; van Rijn, 1993). This stress is generally higher than that induced by currents computed by hydrodynamic processes (Grant and Madsen, 1979; Glenn and Grant, 1987). Hydrodynamic models are based on processes with much longer time scales. Wind waves, on the other hand, are high frequency short waves. These waves are generally considered deep water waves, represented as governing equations (USCOE, 1984; Fredsoe and Deigaard, 1991) which are different than the shallow water wave equations. The computation of bottom shear stress due to wave induced currents is presented below.

The hydrodynamic model provides the near bottom current velocity (U), direction of current (θ_c), and the total water depth (h). The wave model predicts the significant wave height (H_s), period (T) and direction (θ). Linear wave theory is used to translate the wave parameters (H_s and T) into a near-bed peak orbital velocity (U_p) and peak orbital amplitude (A_p) as follows

$$U_p = \frac{\pi H_s}{T \sinh\left(2\pi \frac{h}{L}\right)} \tag{7-18}$$

$$A_p = \frac{H_s}{2 \sinh\left(2\pi \frac{h}{L}\right)} \tag{7-19}$$

where the wave length (L) is given by

$$L = C_o T \tag{7-20}$$

and the shallow water wave speed (C_o) is

$$C_o = \sqrt{g\,h} \tag{7-21}$$

in which g is the gravitational acceleration.

The Grant-Madsen wave-current model (Grant and Madsen, 1979; Glenn and Grant, 1987) is then used to calculate bottom shear stresses due to currents and waves. Inputs to the model are:

U	=	magnitude of the near bottom current velocity
Φ	=	θ - θ_c, the difference between wave and current direction
U_p	=	near-bed peak orbital velocity
A_p	=	near-bed peak orbital amplitude
z_0	=	effective bottom roughness height

Output from the model is the bottom shear velocity (u_*). The bed shear stress (τ_b) is then computed as

$$\tau_b = \rho\, u_*^2 \tag{7-22}$$

where ρ = density of water. In the absence of wave, u_* is a function of U only. The details of bed shear stress computations without wave and current interaction can be found in Blumberg and Mellor (1987).

Surface wind waves can significantly increase bed shear stresses as pointed out in previous studies (Fredsoe and Deigaard, 1991; van Rijn, 1993). The magnitude of the bed shear stress is a function of the characteristics of wind wave field, which is highly variable in time. Bed shear stresses due to the combined effects of waves and currents can result in stresses that are two orders of magnitude higher than stresses resulting from currents alone. These higher stresses may result in significantly different bed erosion and sediment transport. Therefore, effects of wind generated waves may be an important mechanism that should be included in the current modeling framework.

8.1 Finite Difference Formulation

The governing equations form a set of simultaneous partial differential equations which cannot be solved using known analytic methods. The equations require numerical computational methods using discretized equations on a grid. In anticipation of constructing the finite differencing scheme, the governing equations have been cast into their flux form. This is to insure that certain integral constraints are maintained by the differencing.

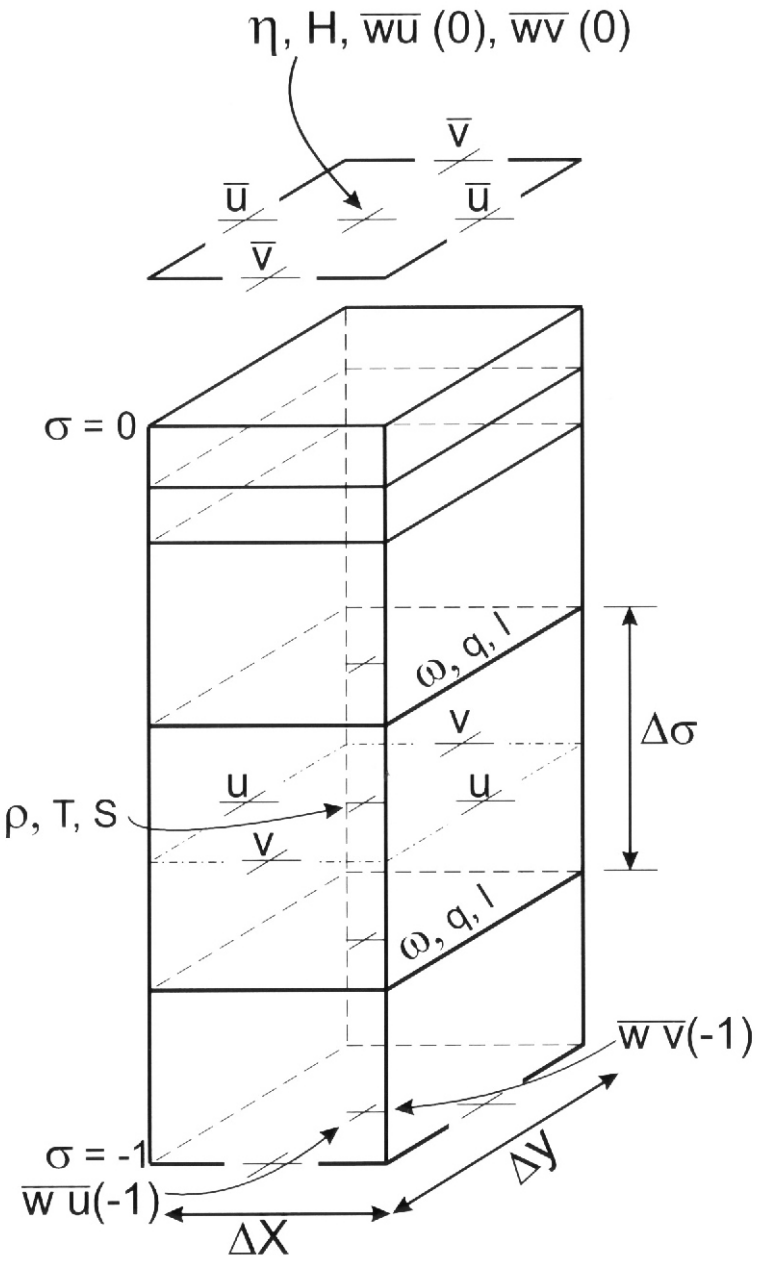
8.1.1 Finite Differencing

The relative positions of the variables on the staggered computation "C" grid are shown in Figure 8-1. The staggered arrangement uses U at points to the east and west of the point where η and H are defined and V at points to the north and south of the η and H points. This type of grid has been shown by Batteen and Han [1981] to be the most effective grid for high resolution models. The Δx and Δy are the constant horizontal grid spacings and $\Delta\sigma$ is the vertical increment which varies in thickness to accommodate more resolution near the surface and bottom.

The finite difference equations used in ECOM can be demonstrated to be of second order accuracy in space and time and to conserve energy, temperature, salinity, mass, and momentum. Finally, the model's computer code has been deliberately designed to be economical on modern array processing computers.

8.1.2 Subgrid Scale Parameterizaton

Horizontal mixing coefficients for both momentum and heat/salinity are used to parameterize all processes which are not resolved on the numerical grid. Typically, these mixing coefficients are chosen such that they are sufficient to provide minimal smoothing without excessive damping of real oceanographic processes. Since the numerical grid can be non-uniform, the mixing coefficients must vary proportionally in order to maintain a uniform grid Reynolds number. The parameterization suggested by Smagorinsky (1963), which also depends on the horizontal grid spacing, has been used in the model.



The locations of the variables on the finite difference grid.

FIGURE 8-1

The terms related to small-scale mixing processes not directly resolved by the model are parameterized as horizontal diffusion as described in Equations (3-39) and (3-44) and calculated according to Smagorinsky 91963):

$$A_M = \alpha \Delta x \Delta y \left[\left(\frac{\partial U}{\partial x} \right)^2 + \left(\frac{\partial V}{\partial y} \right)^2 + \frac{1}{2} \left(\frac{\partial U}{\partial y} \right) + \left(\frac{\partial V}{\partial x} \right)^2 \right]^{1/2} \quad (8\text{-}1)$$

and where the notation is based upon Cartesian coordinates and variable names are those used conventionally. The parameter α is typically equal to 0.10 and has ranged from 0.01 to 0.5 in various applications. Here $A_H = A_M$, but the code has provisions to relax this constraint

8.1.3 Stability Constraints

The leap-frog differencing used for the time stepping introduces a tendency for the solution at even and odd time steps to split. This time splitting is removed by a weak filter [Asselin, 1972] where the solution is smoothed at each time step according to

$$F_s^n = F^n + \frac{\alpha}{2} \left(F^{n+1} - 2F^n + F_s^{n-1} \right) \quad (8\text{-}2)$$

where $\alpha = 0.05$ and F_s is a smoothed solution.

This technique introduces less damping than either the Euler-backward or forward stepping techniques.

The Courant-Friedrichs-Levy (CFL) computational stability condition on the vertically integrated, external mode, transport equations limits the time step as shown by Blumberg and Mellor [1981a] according to

$$\Delta t \le \frac{1}{C_t} \left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} \right)^{-1/2} \quad (8\text{-}3a)$$

where

$$C_t = 2(gH)^{1/2} + \overline{U}_{max} \quad (8\text{-}3b)$$

$\bar{U}$max is the maximum average velocity expected. There are other restrictions but in practice the CFL limit is the most stringent. The model time step is usually 90% of this limit. The internal mode has a much less stringent time step since the fast moving external mode effects have been removed. The time step criteria is analogous to the one for the external mode given above and is

$$\Delta T \le \frac{1}{C_T} \left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} \right)^{-1/2} \quad (8\text{-}4)$$

where $C_T = 2C + U_{max}$, with C being the maximum internal gravity wave speed commonly of order 2 m/s and U_{max} is the maximum advective speed. For typical coastal ocean conditions the ratio of the time steps, $\Delta T/\Delta t$, is often a factor of 3-100.

Diffusion is important in the internal mode but does not affect the overall choice of time step, unless the grid Reynolds number is of order 1, in which case

$$\Delta T < \frac{1}{4A_H}\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}\right)^{-1} \tag{8-5}$$

must be used.

A rotational condition is

$$\Delta t < \frac{1}{f} = \frac{1}{2\Omega \sin\theta} \tag{8-6}$$

where Ω is the angular velocity of the earth and θ is the latitude. However, even for high latitudes the rotational condition is not a limiting factor.

8.2 Advection Algorithms

Accurately simulating the transport of salinity, temperature, sediment and tracers can be difficult, particularly in hydrodynamic and sediment transport problems involving the propagation of steep gradients, or fronts. In estuarine and coastal problems, the propagation of fronts is important, particularly in the zone where freshwater and saltwater mix. Three algorithms, each of which may provide distinct advantages for a particular problem, are available for use in ECOMSED: central difference, upwind difference and the Multidimensional Positive Definite Advection Transport Algorithm (MPDATA).

The central difference algorithm is second-order accurate, generates no numerical diffusion and is computationally efficient. However, this method is not positive definite and negative salinities/ temperatures/sediment concentrations, which are physically impossible, may be generated in certain types of hydrodynamic and sediment transport problems. In addition, numerical ripples may be generated ahead of and behind fronts. Upwind differences are only first-order accurate and may introduce significant numerical diffusion into a solution depending upon typical current speeds and grid sizes. An advantage of upwind transport is that the algorithm is positive definite and the most computationally efficient of any of the advective schemes.

An improvement over both the central and upwind methods, particularly with regard to the transport of fronts, is MPDATA, which is described in detail by Smolarkiewicz (1984), Smolarkiewicz and Clark (1986) and Smolarkiewicz and Grabowski (1990). The general concept used in MPDATA is the successive application of an upwind transport algorithm, which is first-order accurate and positive definite, such that numerical diffusion, generated by a first-order truncation error, is minimized. A correction to the first-order truncation error is made by reapplying the upwind algorithm, after the initial upwind step, using an "anti-diffusion" velocity that is based on the local first-order truncation error. The corrective step may be applied an arbitrary number of times, resulting in a successive reduction in the numerical diffusion generated by the initial upwind step. This procedure yields an advection algorithm that is second-order accurate, and positive definite. Furthermore, MPDATA preserves the local monotone character of the advection field, such that,

the field is free of numerically-generated ripples, provided that the anti-diffusion velocities are property bounded. The greatest drawback to routine use of MPDATA is its large demand for computational resources. The execution time for a typical simulation can double the time required for a case involving central or upwind differences. On vector computers this factor is even larger because of the unavoidable many "IF" statements needed in the computer code.

8.3 Thin Dams

The model can be configured to represent thin obstructing structures such as groins, wave breakers, or dams. No flow exchange will be allowed between two grid cells separated by these thin dams. This feature is particularly useful to model harbor facilities where flow around thin and elongated man-made structures needs to be modeled without masking out grid cells. Designation of thin dam follows the same conventions for computational variables shown in Figure 8-1.

8.4 Semi-Prognostic Density Computations

When the model is configured with climatological temperature and salinity data and run in prognostic mode, often times model computation becomes unstable over time. This is mainly due to departures of initial temperature and salinity in prognostic computations which were caused by internal mixing, bottom friction, and flows across steep bathymetric slope along the open water boundaries. Nevertheless, this is mainly due to the insufficient boundary information prescribed along the boundary locations. The sea level fluctuations induced by density and weather related events are absent from the input data. The combined effect of insufficient sea level boundary conditions and dynamic density field, which is not supported by computed and prescribed temperature and salinity boundary conditions, induces artificial noise along the boundary cells and eventually causes model to crash. In order to solve these problems, a numerical technique suggested by Sheng et. al.(2001) was implemented. This procedure is equivalent to adding a forcing term to the momentum equations by modifying the horizontal pressure gradient term seen by the model (Sheng et. al, 2001).

In order to solve the pressure gradients over depth, the equation becomes.

$$\frac{\partial p}{\partial z} = \left[\alpha\rho_m + (1-\alpha)\rho_d\right]g \qquad (8\text{-}7)$$

p = pressure
ρ_d = Initial T/S derived from data
ρ_m = Model computed T/S
α = coefficient (0 to 1) If $\alpha = 1$, pure prognostic. If $\alpha = 0$, pure diagnostic.

The equation denotes that the model solution adjusts its pressure gradients with initially specified density field(ρ_d) and computed density(ρ_m).

8.5 Empirical Vertical Turbulent Mixing

The Mellor-Yamada turbulence model can yield accurate hydrodynamic simulations. However, use of this approach typically requires using about 10 levels in the vertical. For many problems, this level of vertical resolution is impractical, due to constraints on data, time or budget. Another method to simulate the effects of turbulence on vertical mixing processes is use of an empirical formula. This approach can be quite useful

for problems that require use of low vertical resolution.

The empirical vertical mixing theory is based on ideas of Kent and Pritchard (1959) and Officer (1976). There are two adjustable coefficient α and β which set the amount of mixing at a location. They can be thought of as proportional to the bottom roughness. They are unitless scaling factors.

$$K_M = K_o \left(1+\beta R_i\right)^{-1} \tag{8-8}$$

$$K_H = K_o \left(1+\beta R_i\right)^{-2} \tag{8-9}$$

with

$$K_o = \alpha Z^2 \left(1+\frac{z}{D}\right)^2 \left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]^{1/2} \tag{8-9a}$$

$$R_i = -\frac{\frac{g}{\rho}\frac{\partial \rho}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}\right)^2} = \frac{\text{buoyancy}}{\text{shear}} \tag{8-9b}$$

Note: turbulent Prandtl number is

$$Pr = \frac{K_H}{K_M} = \frac{1}{1+\beta R_i} \tag{8-9c}$$

Several test simulations with stratified conditions suggest that the values of 0.01 ~ 1.0 for coefficient α and 0.1 ~ 1.0 for β can be used. However, it is advised to experiment with sufficient ranges of α and β for the sensitivity in a particular model application.

8.6 netCDF Output Format

ECOMSED has utilized universally accepted network compatible data format (netCDF) for its output. This data format is portable to any computer systems. Many utility programs are available in scientific community.

8.7 Flooding and Drying

A physical feature of flooding and drying of tidal flats based upon Flather and Heaps (1975) has been incorporated into ECOMSED. The treatment is based on both total water depth (D = H + h) and elevation gradient with adjacent grid cells. For implementation of the flooding and drying scheme, a minimum threshold depth (Dmin) and a critical elevation gradient (e) are pre-assigned (via model input). Figure 8-2 illustrates ECOMSED grid conventions. At each external computational timestep, Di,j, Di+1,j and Di,j+1 are checked (Figure 7-2). The procedure to determine whether a grid cell is either "wet" or "dry" is illustrated

in Figure 8-3 (Kim, 1999) and depends upon whether the D and elevation gradient (Dh) are greater or less than Dmin and e, respectively. A land cell is always "dry" and a water cell can be "wet" or "dry". To insure that a water cell is always "dry", the cell can be initialized with a large negative value of H or can be pre-defined as a land cell. But for the conservation of mass and momentum, ECOMSED requires a non-zero water depth be specified (initialized) in the model domain.

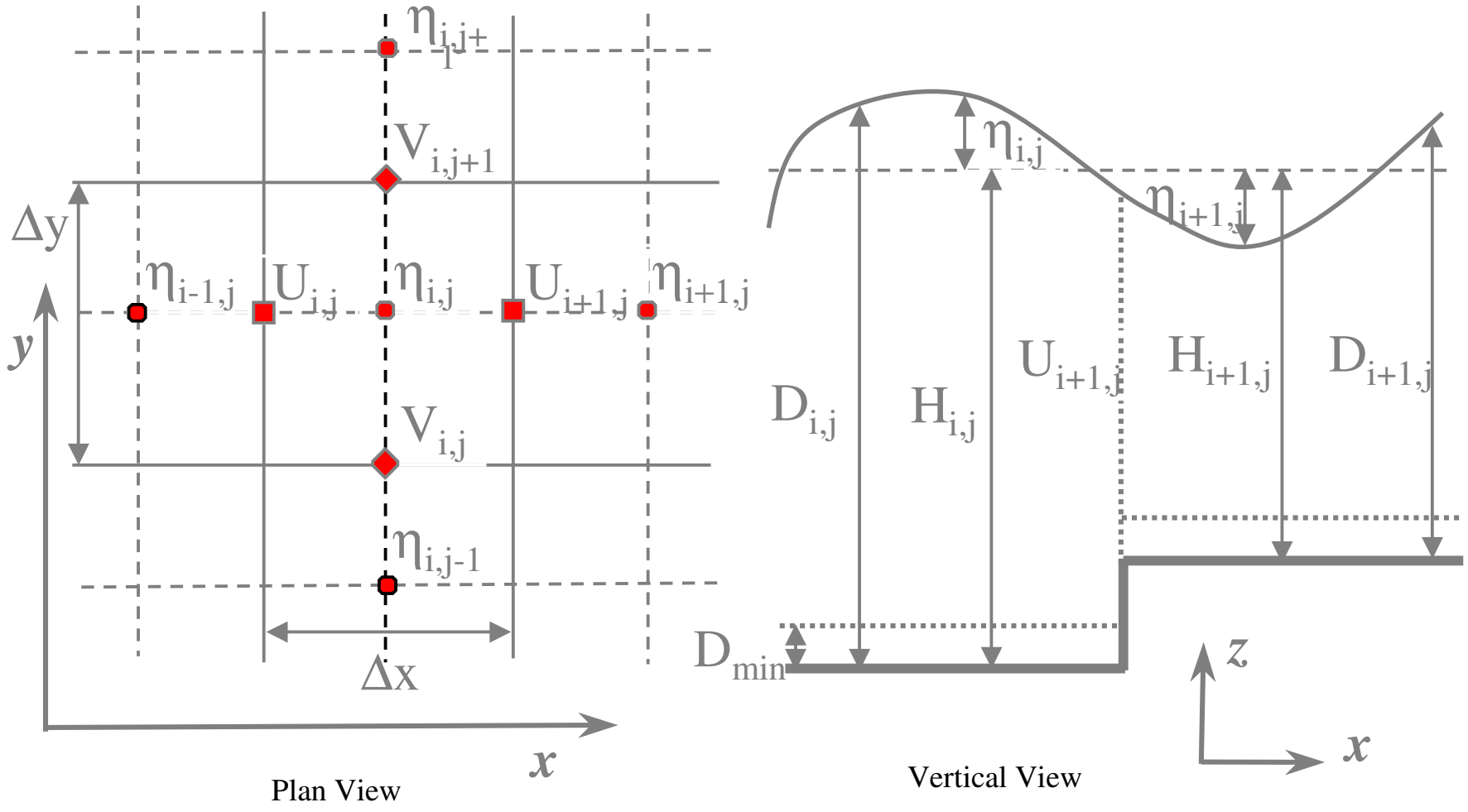
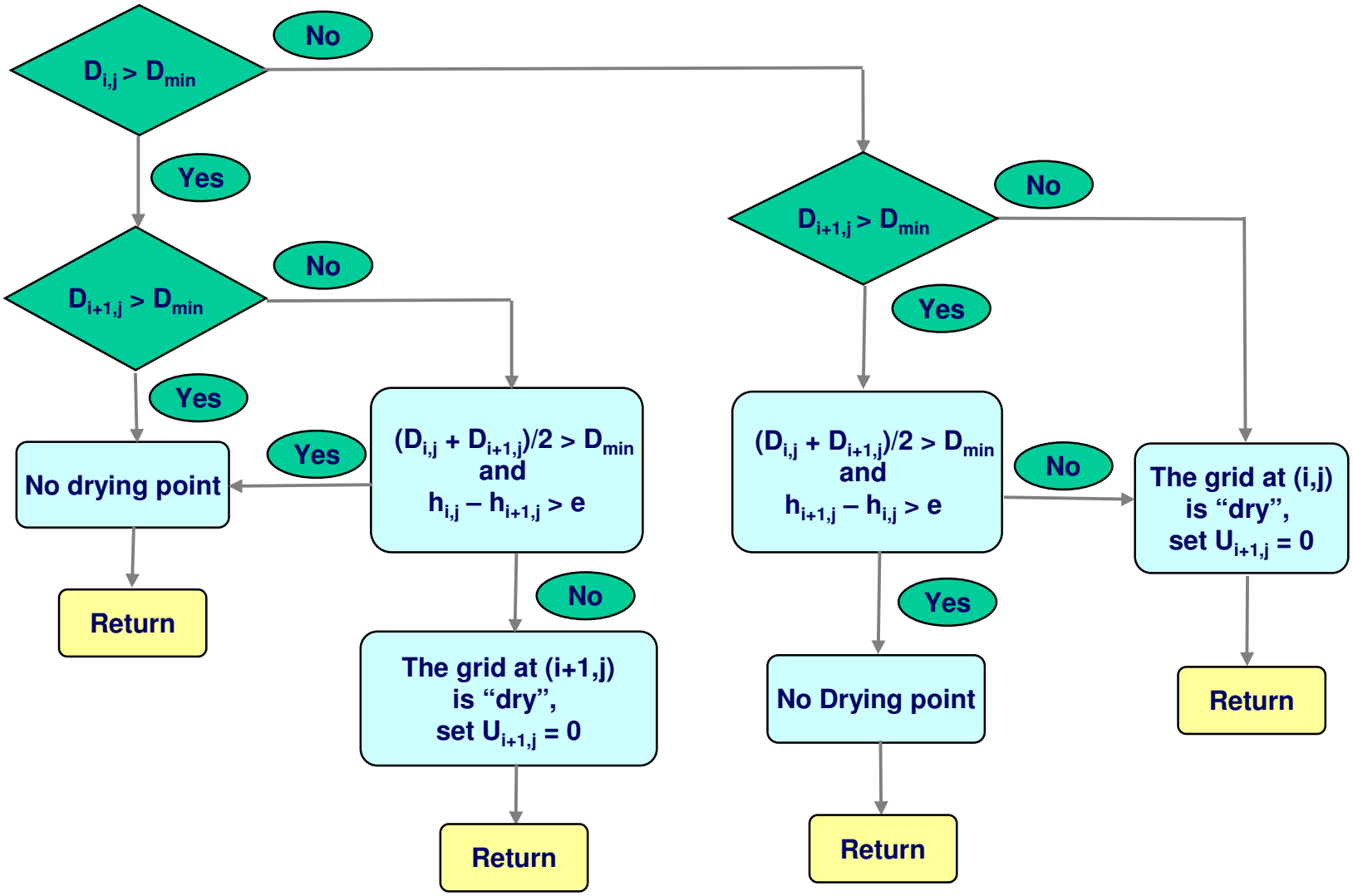


Figure 8-2. Schematic illustration of the ECOMSED Grid



After Flather and Heaps 1975 & Kim 1999

Figure 8-3. Flow chart of wetting/drying scheme

9.0 Structure of Computer Code

9.1 Fortran Symbols

The FORTRAN symbols followed by their corresponding analytical symbols in parentheses and a brief description of the symbols are listed in Table 9-1.

Table 9-1. Fortran Symbols

Indices	Description
I, J (i,j)	horizontal grid indexes
IM, JM	outer limits of I and J
K (k)	vertical grid index; K = 1 at the top and K = KB at the bottom
INT	internal mode time step index
IEXT	external mode time step index
Constants	
DTE (Δt_E)	external mode time step, (s)
DTI (Δt_I)	internal mode time step, (s)
EXTINC	short wave radiation extinction coefficient, (m^{-1})
HORCON(C)	the coefficient of the Smagorinsky diffusivity
IEND	total internal model time steps
IPRINT	the interval in IINT at which variables are printed
ISPLIT	DTI/DTE
MODE	if MODE =2, a 2-D calculation is performed if MODE =3, a 3-D prognostic calculation is performed if MODE =4, a 3-D diagnostic calculation is performed
RFE, RFW, RFN, RFS	1 or 0 on the four open boundaries; for use in BCOND
SMOTH (α)	parameter in the temporal smoother
TPRNI (A_H/A_M)	inverse, horizontal, turbulence Prandtl number
TR	short wave surface transmission coefficient
UMOL	background vertical diffusivity
One-dimensional Arrays	
Z(σ)	sigma coordinate which spans the domain, Z = 0 (surface) to Z = -1 (bottom)
ZZ	sigma coordinate, intermediate between Z
DZ($\delta\sigma$)	= Z(K)-Z(K+1)
DZZ	= ZZ(K)-ZZ(K+1)
Two-dimensional Arrays	
AAM2D	vertical average of AAM (m^2s^{-1})
ART, ARU, ARV	cell areas centered on the variables, T, U and V respectively (m^2)
ADVUA, ADVVA	sum of second, third and sixth terms in equations (3-46, 3-47)
ADX2D, ADY2D	vertical integrals of ADVX, ADVY
COR(f)	the Coriolis parameter (s^{-1})
CURV2D	the vertical average of CURV

Table 9-1. Fortran Symbols (Cont.)

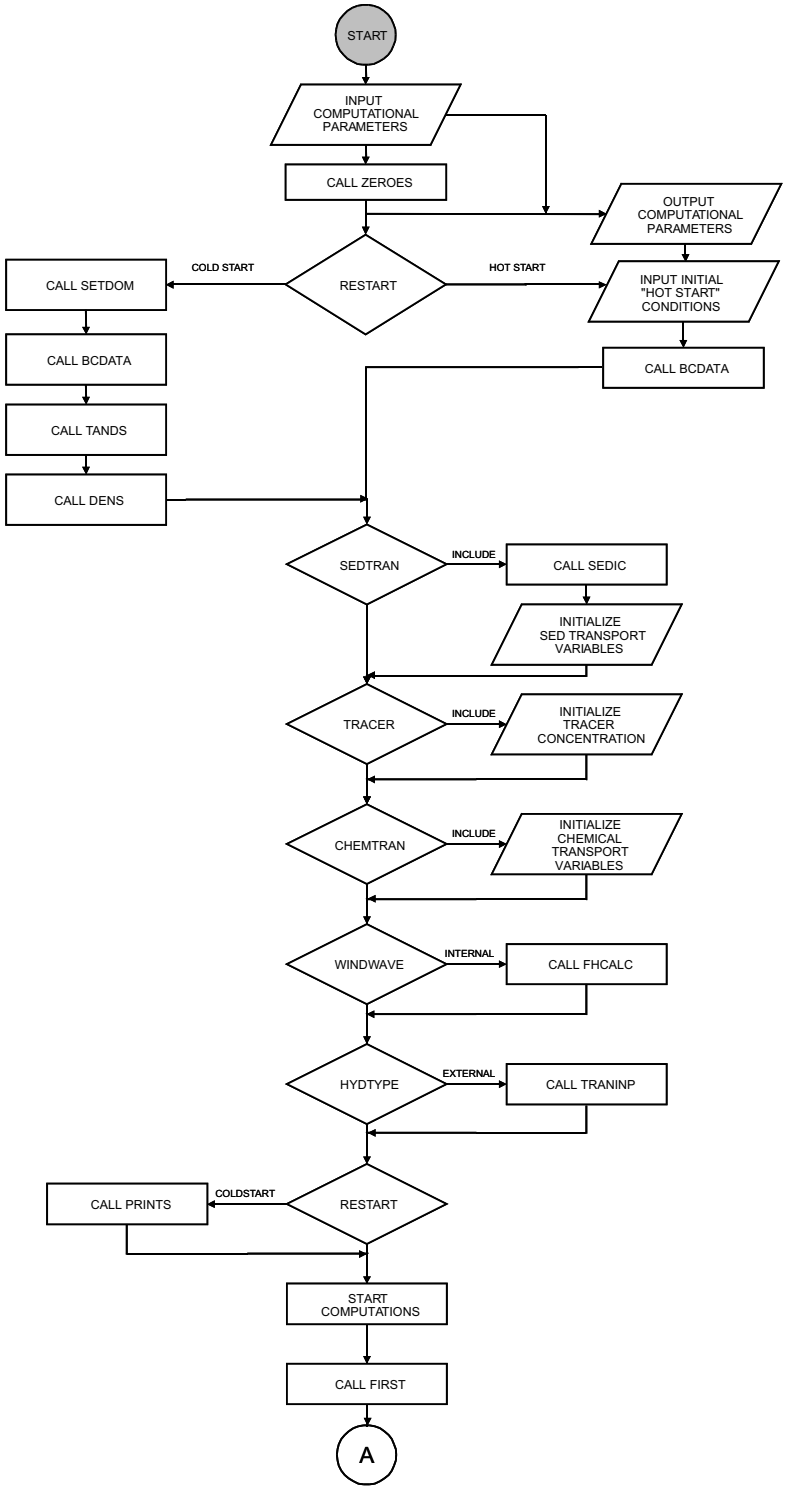
Indices	Description
DUM	Mask for the *u* component of velocity; = 0 over land; =1 over water
DVM	Mask for the v component of velocity; = 0 over land; =1 over water
FSM	Mask for scalar variables; = 0 over land; =1 over water
DX(h_x or δ_x)	grid spacing (m)
DY(h_y or δ_y)	grid spacing (m)
EL (η)	the surface elevation as used in the external mode (m)
ET (η)	the surface elevation as used in the internal mode and derived from EL (m)
EG (η)	the surface elevation also used in the internal mode for the pressure gradient and derived from EL (m)
D (D)	= H + EL (m)
DT (D)	= H + ET (m)
DRX2D, DRY2D	vertical integrals of DRHOX and DRHOY
H (H)	the bottom depth (m)
SWRAD	short wave radiation incident on the ocean surface (m s^{-1}K)
UA, VA, $(\overline{U},\overline{V})$	vertical mean of U, V (m s^{-1})
UT, VT, $(\overline{U},\overline{V})$	UA, VA time averaged over the interval, DT = DTI (m s^{-1})
WUSURF, WVSURF	(<wu(0)>,<wv(0)>) momentum fluxes at the surface (m^2s^{-2})
WUBOT, WUBOT	(<wu(-1)>,<wv(-1)>) momentum fluxes at the bottom (m^2s^{-2})
WTSURF, WSSURF	(<wθ(0)>,<ws(0)>) temperature and salinity fluxes at the surface (ms^{-1} K, ms^{-1} psu)
Three-Dimensional Arrays	
ADVX, ADVY	horizontal advection and diffusion terms in equations (3-2) and (3-3)
AAM (A_M)	horizontal kinematic viscosity ($m^2 s^{-1}$)
AAH (A_H)	horizontal heat diffusivity = TPRNI*AAM
CURV $(\tilde{f})$	curvature terms
L (ℓ)	turbulence length scale
KM (K_M)	vertical kinematic viscosity ($m^2 s^{-1}$)
KH (K_H)	vertical diffusivity ($m^2 s^{-1}$)
DRHOX	x-component of the internal baroclinic pressure gradient
$\left(gDh_y\rho_0^{-1}\left[-D\int_\sigma^0 \delta_x\rho'\delta\sigma' + \delta_x D\int_\sigma^0 \sigma'\delta\rho'\right]\right)$	subtract RMEAN from density before integrating
DRHOY	*y*-component of the internal baroclinic pressure gradient
$\left(gDh_x\rho_0^{-1}\left[-D\int_\sigma^0 \delta_y\rho'\delta\sigma' + \delta_y D\int_\sigma^0 \sigma'\delta\rho'\right]\right)$	subtract RMEAN from density before integrating
RAD (R)	short wave radiation flux (ms^{-1}K). Sign is the same as WTSURF

Table 9-1. Fortran Symbols (Cont.)

Indices	Description
Q2 (q^2)	twice the turbulence kinetic energy (m^2s^{-2})
QL ($q^2\ell$)	Q2 × the turbulence length scale (m^3s^{-2})
T (T)	potential temperature (K)
S (S)	salinity (psu)
RHO (ρ/ρ_o-1.025)	density (non-dimensional)
U, V (U, V)	horizontal velocities (m s^{-1})
W (ω)	sigma coordinate vertical velocity (m s^{-1})
RMEAN	density field which is horizontally averaged before transfer to sigma coordinates.
TCLIM	a stationary temperature field which approximately has the same vertical structure as T.
SCLIM	a stationary salinity field which approximately has the same vertical structure as S.

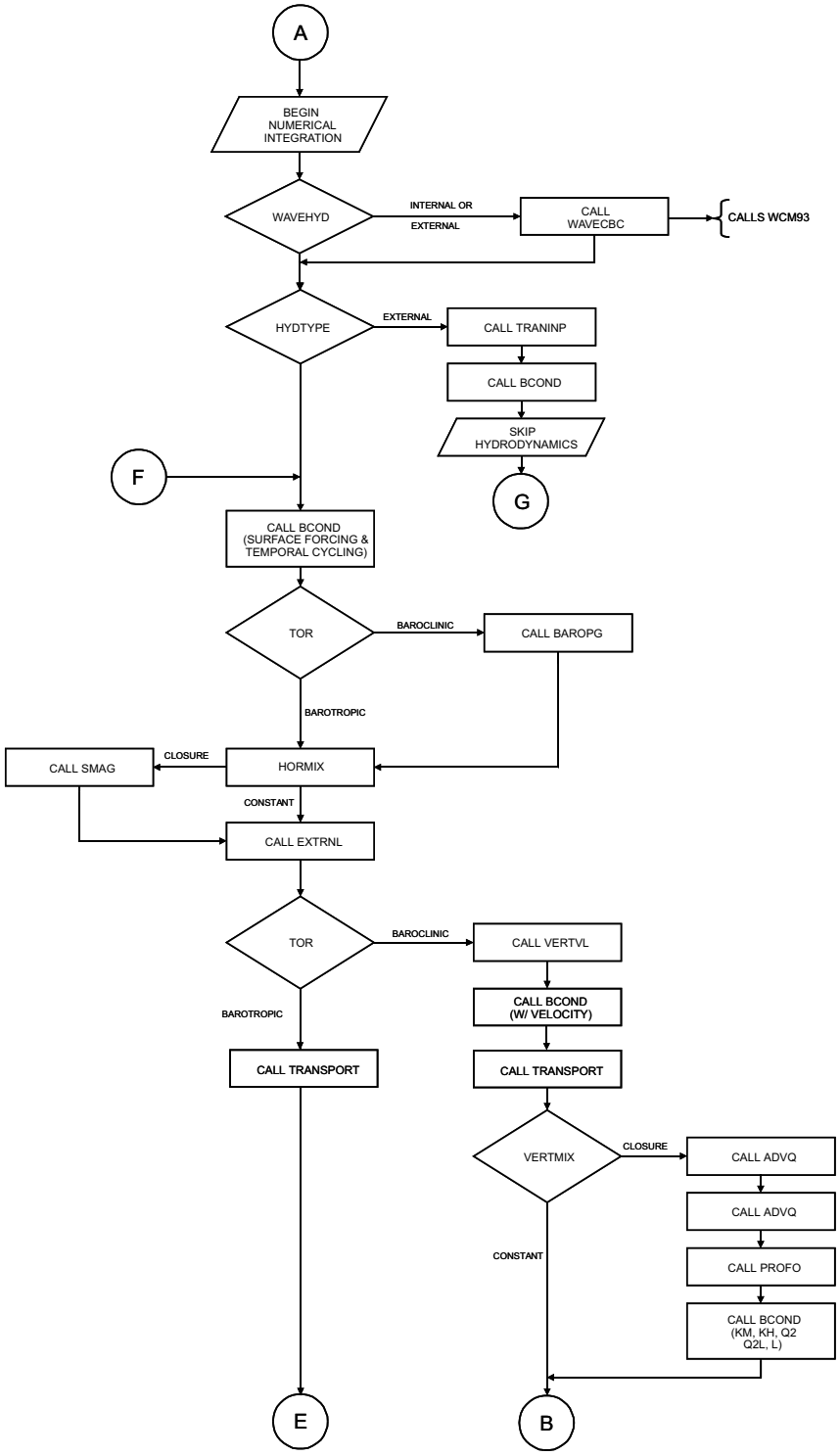
9.2 Program Structure

The ECOMSED computer programs consist of a main program and a set of subroutines. The main program and subroutines contain approximately 15,000 lines of code and they share a common file of some 100 or so records. The file "comdeck" must be edited for new values of IM, JM, KB or KSL (number of standard level). The various components of the computer programs are listed in Table 9-2. Figure 9-1 is the flow chart for the programs in simplified form. The code is written in a modular fashion so that various "physics" packages can be inserted easily. For example, SUBROUTINE PROFQ solves for the vertical mixing coefficients (eddy viscosity and eddy diffusivity). If forms other than the presently implemented level 2-1/2 turbulence closure model are desired, they can be incorporated in a new subroutine and PROFQ discarded. Much care has gone into the design of a code that is fully vectorizable. The use of "IF" statements has been greatly minimized. The code has a five fold increase in speed when running with vectorization "on" on a Cray X-MP/48 supercomputer.



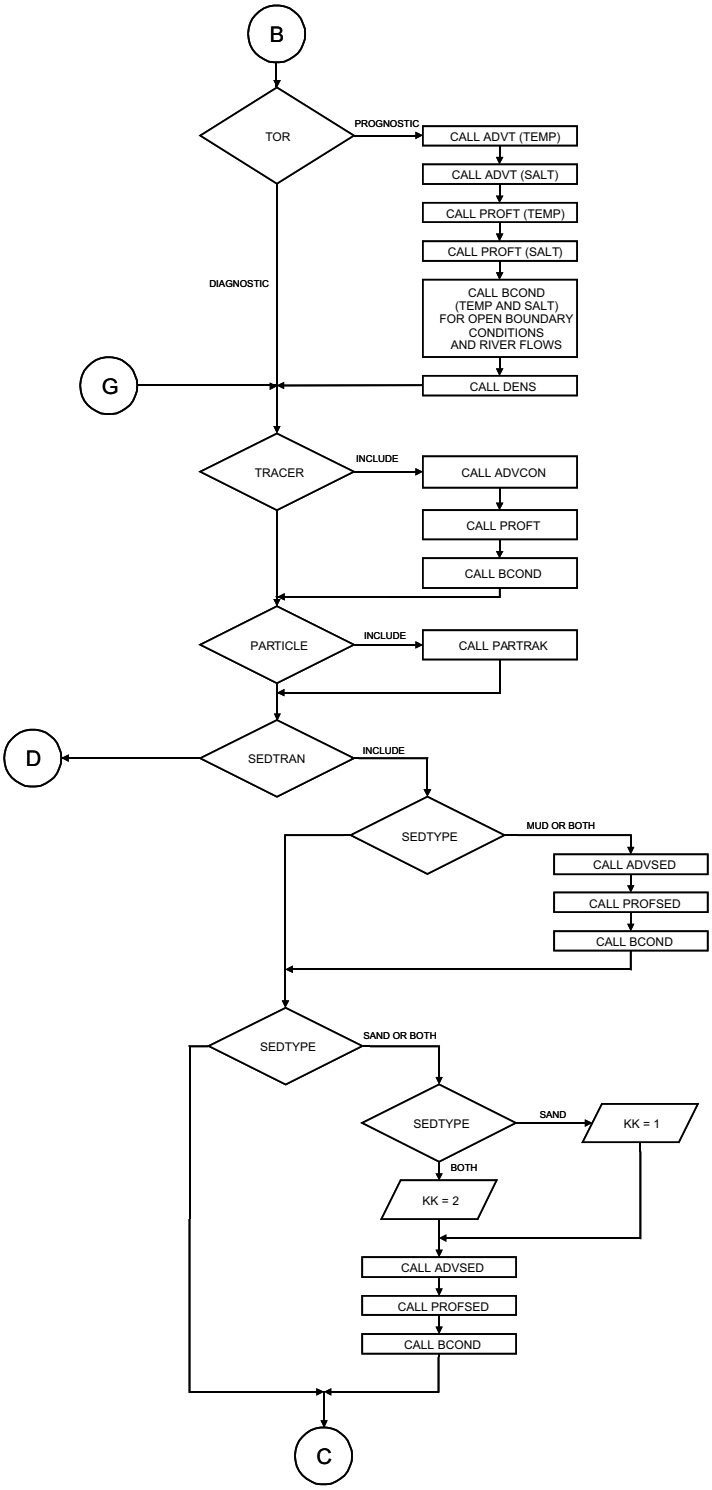
ECOMSED flowchart.

FIGURE 9-1



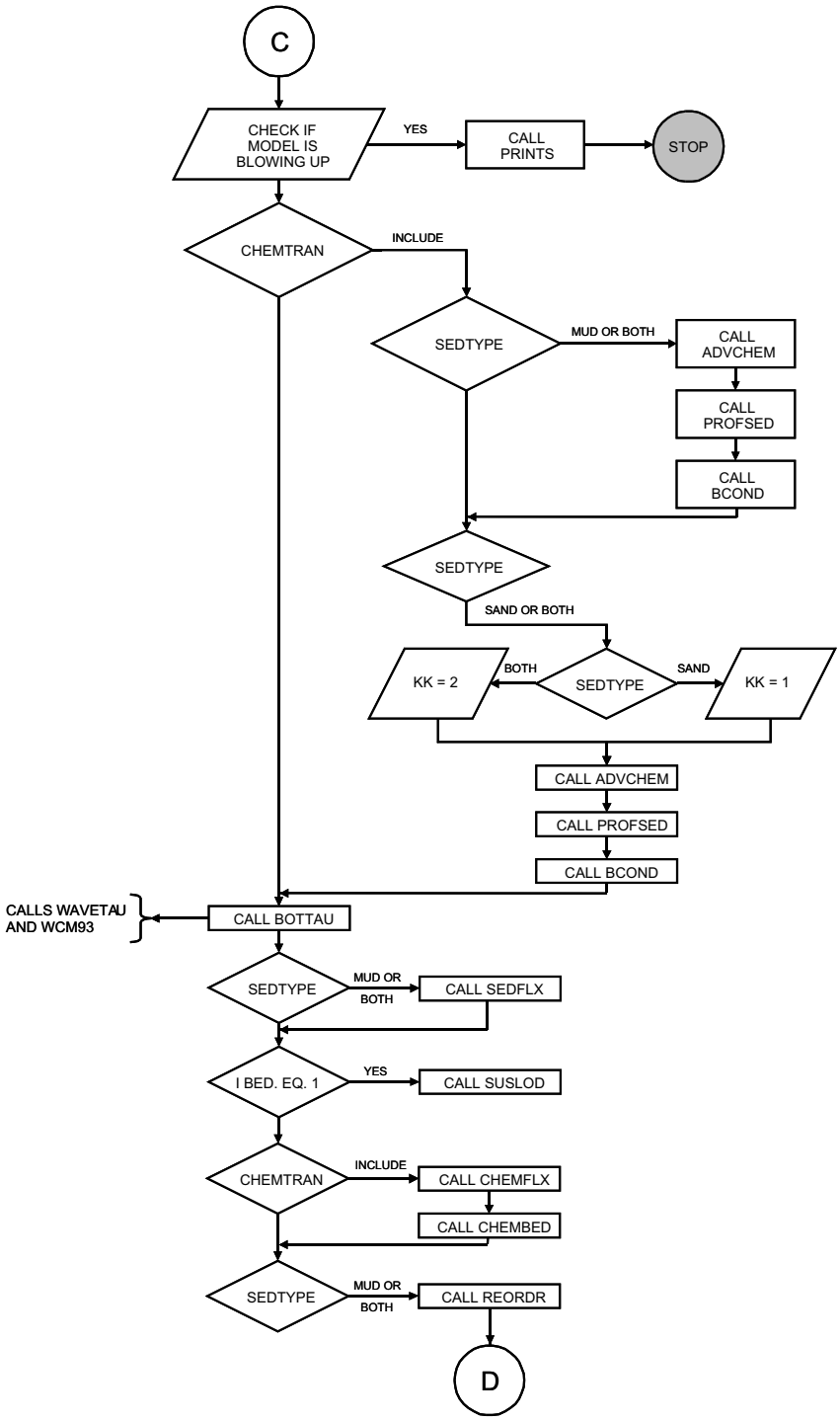
ECOMSED flowchart.

FIGURE 9-1 (continued)



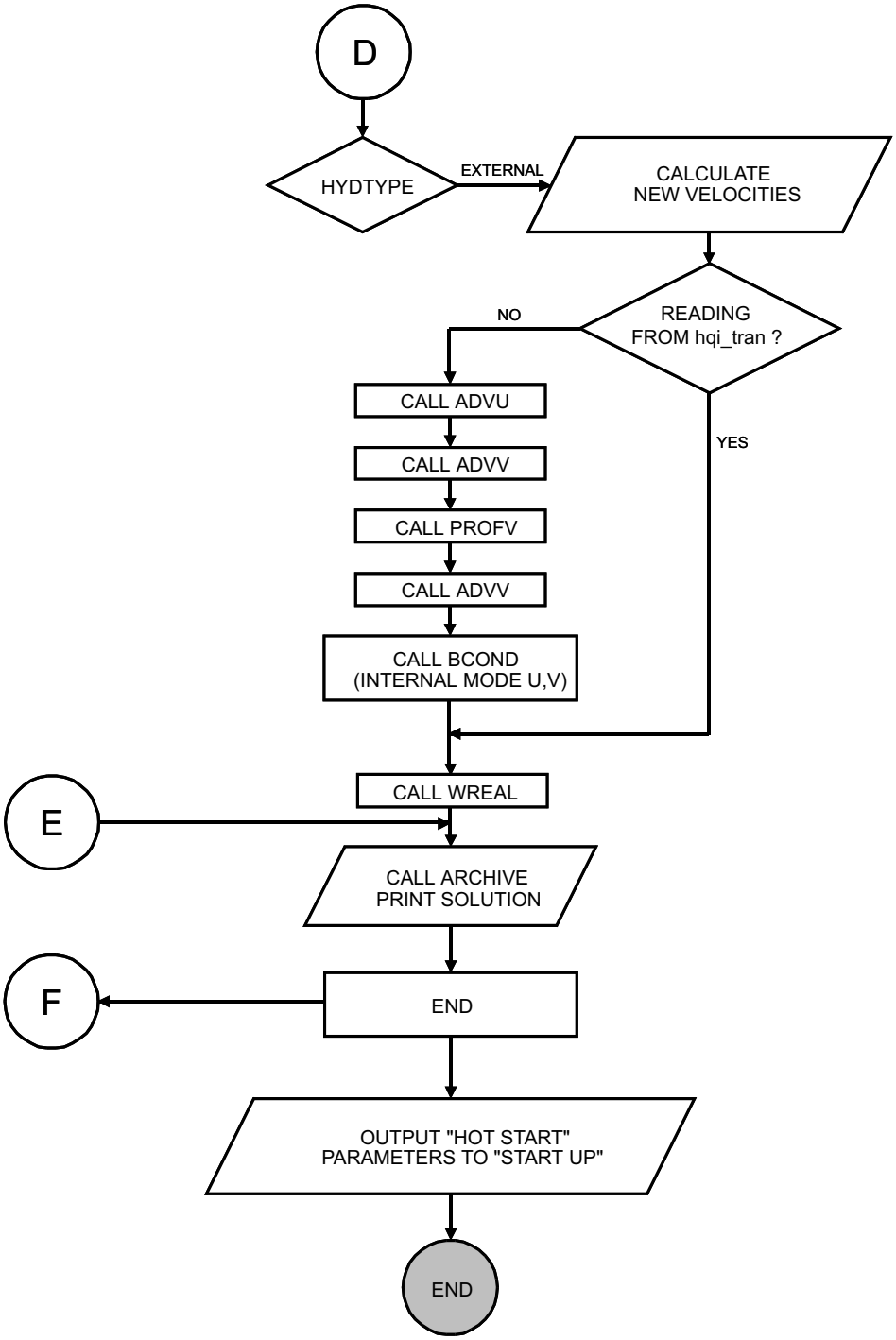
ECOMSED flowchart.

FIGURE 9-1 (continued)



ECOMSED flowchart.

FIGURE 9-1 (continued)



ECOMSED flowchart.

FIGURE 9-1 (continued)

Table 9-2. Components of the Computer Programs

Subroutines	Description
ADVAVE	Computes the advective and dispersive terms in the ξ_1 andξ_2 components of the vertically integrated momentum equation
ADVCHEM	Computes advective and dispersive terms in sediment-bound tracer transport equation
ADVCON	Computes advective and dispersive terms in dissolved tracer transport equation
ADVQ	Computes the advective and dispersive terms in the turbulence kinetic energy and macroscale equations
ADVSED	Computes advective and dispersive terms in sediment transport equation
ADVT	Computes the advective and dispersive terms in the mass transport equation
ADVU	Computes the advective, Coriolis, pressure gradient and dispersive terms in the ξ_1 component of the momentum equation
ADVV	Computes the advective, Coriolis, pressure gradient and dispersive terms in the ξ_2 component of the momentum equation
ANTIDIF	Computes anti-diffusion velocities for use in Smolarkiewicz transport algorithm
ARCHIVE	Time averages and writes to disk various quantities useful for graphical analyses
BAROPG	Computes the baroclinic pressure gradient terms through the vertical integral of the horizontal density gradient
BCDATA	Reads in the boundary condition data and performs the necessary interpolation for the model run
BCOND	Specifies the lateral and surface boundary conditions. Cycles through the input files when necessary
BOTTAU	Computes bottom shear stresses for sediment transport model
BULK	Computes sensible heat and latent heat
CHEMBED	Calculates changes in sediment bed concentrations of sediment-bound tracer
CHEMFLX	Calculates flux of sediment-bound tracer at sediment-water interface
COMDECK	Contains all paramters, type specifications, dimensions and common blocks to be included in the main program and subroutines. COMDECK should be edited for new values of IM, JM, KB and KSL.
DENS	Computes the local density of water from the most recent values of temperature and salinity. The program actually uses ρ-1
DISPLY	Writes a two dimensional array to the "gcmprt" file

Table 9-2. Components of the Computer Programs

Subroutines	Description
ECOM3D	Controls and monitors the flow of the particular simulation. This is the main program
EXTRNL	Solves for the depth integrated U and V velocities
FHCALC	Calculates fetch and mean depth for wind wave model
FIRST	Prepares the first set of data for use in the time variable model run
FZOL	Estimates stability functions for heat flux calculation
JDAY	Gives Julian day number
LONGWAVE	Computes longwave radiation
MAXMIN	Finds the maximum and minimum values of an array
N_CLOUD	Estimates total shortwave radiation reaching the earth surface and cloud cover fraction (0.0 to 1.0)
NCLD	Calculates percent cloud cover based on observed shortwave radiation and day of the year
ONEPART	Particle tracking algorithm
PARTRAK	Controls particle tracking simulations
PRINT	Writes a two dimensional array to the "gcmprt" file in an integer format
PRINTS	Controls the printing of the various model quantities
PROFE	Solves for empirical vertical mixing coefficients
PROFQ	Solves for turbulence kinetic energy, turbulence macroscale, and the vertical mixing coefficients for momentum, and temperature and salinity
PROFT	Solves for temperature, salinity and conservative tracer
PROFU	Solves for the U velocity
PROFV	Solves for the V velocity
PRTXY	Selects a horizontal field for use in PRINT
QSAT	Calculates saturation humidity
REORDR	Reorders sediment layers due to consolidation
SEDFLX	Calculates sediment flux at sediment-water interface
SEDIC	Initializes sediment transport constants and variables
SETDOM	Defines the physical characteristics of the model domain and the particular run and computes various constants to expedite the computation
SINTER	Interpolates various data profiles to model depths from their observed depth

Table 9-2. Components of the Computer Programs

Subroutines	Description
SLICEXZ	Writes a vertical slice in the x-direction of a three dimensional array to the "gcmprt" file
SLICEYZ	Writes a vertical slice in the y-direction of a three dimensional array to the "gcmprt" file
SMAG	Computes the coefficient of horizontal viscosity
STRESS	Calculates bottom shear stress due to wind induced waves and currents
SUSLOD	Calculates non-cohesive sediment suspended load
TANDS	Prepares the initial temperature and salinity fields for use in the model calculation
TRANINP	Reads external hydrodynamic information from "hqi_geom" and "hqi_tran" files
TRANSPORT	Calculates mean mass transport fields for use with a water quality model
VAPOR	Computes vapor pressure
VERTVL	Solves for the vertical velocity
WAVEDON	Calculates wave parameters based on Donelan (1977)
WAVESMB	Calculates wave parameters based on United States Army Corps of Engineers Shore Protection Manual (1984)
WREAL	Computes the vertical velocity in real x, y, z space
ZEROES	Sets all computational arrays to initial zeroes and values

The information necessary to make a complete ECOMSED model run is contained in 24 files, briefly described in Table 7.3. Also described briefly in Table 7-3 are the model generated output files and are followed by detailed descriptions of the contents of certain output files.

Table 9-3. Mass Storage Files

	User Created Files	Description
1.	model_grid	Contains the physical information for the model grid (needed if HYDTYPE = "INTERNAL")
2.	init_tands	Contains the initial conditions for temperature and salinity in each water grid box at the standard levels noted in run data (needed if HYDTYPE = "INTERNAL")
3.	run_data	Contains parameters which control the type and length of the simulation. The frequency of various outputs is also included here, along with some of the important problem constants
4.	synop_wind	Contains time variable wind components and atmospheric pressure for the entire model grid. This file is an unformatted input file
5.	synop_hflx	Contains time variable surface heat flux data for the entire model grid. This file is an unformatted input file
6.	corner_loc	Contains corner locations of grid elements, used for wind wave simulations when WAVEHYD = "INTERNAL" and needed for particle tracking simulations
	NOTE	The following user created file is needed for dissolved tracer transport calculations (TRACER = "INCLUDE")
7.	water_tracer.inp	Contains input parameters and boundary condition values for dissolved tracer transport.
	NOTE	The following user created files are needed for sediment transport calculations (SEDTRAN = "INCLUDE")
8.	coh_sed.inp	Contains input parameters and boundary condition values for cohesive sediment transport (needed if SEDTYPE = "MUD " or "BOTH")
9.	noncoh_sed.inp	Contains input parameters and boundary condition values for non-cohesive sediment transport (needed if SEDTYPE = "SAND" or "BOTH"
10.	bed_mask	Contains sediment bed map for the entire model grid
11.	p0_init	Contains initial values of spatially-variable cohesive bed fractions for the entire model grid
12.	a0_init	Contains spatially-variable a_o values for the entire model grid
13.	exp_init	Contains spatially-variable values of exponent n for the entire model grid
14.	bed_d50	Contains spatially-variable D_{50} values for the entire model grid
15.	bed_frac.mud	Contains spatially-variable cohesive composition fractions for the entire model grid, clay/silt fraction
16.	bed_frac.sand	Contains spatially-variable cohesive composition fractions for the entire model grid, sand fraction
17.	bed_bulkden	Contains spatially-variable sediment bed bulk density for the entire model grid
	NOTE	The following user created files are needed for sediment-bound tracer transport calculations (CHEMTRAN = "INCLUDE" and SEDTRAN = "INCLUDE")
18.	coh_trace.inp	Contains input parameters and boundary condition values for cohesive sediment-bound tracer transport (needed if SEDTYPE = "MUD " or "BOTH")

Table 9-3. Mass Storage Files

User Created Files	Description
19. noncoh_trace.inp	Contains input parameters and boundary condition values for non-cohesive sediment-bound tracer transport (needed if SEDTYPE = "SAND" or "BOTH")
20. bed_chemic	Contains spatially-variable initial bed concentrations for sediment-bound tracer, for the entire model grid
NOTE:	The following user created file is needed for particle tracking calculations (PARTICLE = "INCLUDE")
21. partrack.inp	Contains input parameters for particle tracking
NOTE:	The following user created files are needed for simulations using externally-calculated hydrodynamics (HYDTYPE = "EXTERNAL")
22. hqi_geom	This file contains grid segmentation information to be used for transport calculations
23. hqi_tran	This file contains the computed results as a time history for surface elevations and hydrodynamic advection/dispersion fields to be used for transport calculations
NOTE	The following user created file is needed for simulations using externally-calculated wind wave fields (WAVEHYD = "EXTERNAL")
24. wave_input	This file contains computed results as a time history for wind wave parameters as calculated using a wind wave model (e.g., WAM or HISWA
Model Generated Files	**Description**
1. gcmprt:	This file is a main output file containing all the input information and all the computed values
2. gcmplt	This file contains the computed results as a time history for all grid elements. It is useful for graphical analyses
3. gcmtsr	This file contains the computed values of elevation, current, temperature and salinity, and cross sectional fluxes for user specified grid elements. This file also contains the run-time global integrals of various parameters to assist in the diagnosis of the model
4. gcm_tran	This file contains the computed results as a time history for surface elevations, volume transports and dispersions to be used by a water quality model
5. gcm_geom	This file contains grid segmentation information to be used by a water quality model
6. startup	This file contains all the information for the hydrodynamic model run which will become the initial conditions for the "HOT START" runs
7. restart	This file is similar to the "startup" file. User should move or copy the "startup" file to "restart" before making the next "HOT START" run

10.0 Model Input Data Structure

This section provides a detail description of data structure of 24 input data files and selected output files. The names of the input/output files are listed in Section 7.

10.1 Model Geometry Input Data

The input file name is model_grid. There are three data groups in this input file (Table 10-1A).

Table 10-1A: model_grid data structure

Data Group	Description
A.	Comment for Grid Information
B.	Vertical Segmentation
	Comment
	Number of sigma levels
	Sigma levels
C.	Horizontal Segmentation
	Comment
	I index and J index
	Grid Information

NOTE: The model_grid file is only needed if HYDTYPE = "INTERNAL".

Table 10-1B describes in detail format of the data structure in model_grid.

Table 10-1B: model_grid data format

Data Group A: Comment for Grid Information

80
COM
80A1

COM = user specified comment for grid information

Data Group B: Vertical Segmentation

1. Comment

80
COM
80A1

COM = user specified comment for sigma levels

2. Number of Sigma Levels

5
IKB
I5

IKB = number of sigma levels

3. Sigma Levels

10
Z
F10.5

Z = depth of the interface between sigma levels
$-1.0 \leq Z \leq 0.0$

NOTE: Total number = IKB.

Data Group C: Horizontal Segmentation

1. Comment

80
COM
80A1

COM = user specified comment for horizontal segmentation

2. I Index and J Index

5	10
IIX	IJY
2I5	

IIX = index in the ξ_1 direction
IJY = index in the ξ_2 direction

3. Grid Information

5	10	20	30	40	50	60	70	75	80
I	J	H1	H2	H	ANG	YGRID	XGRID	DATUM	
2I5,4F10.2,2F10.5,F5.1,I5									

I = I number of grid element in the ξ_1 direction
J = j number of grid element in the ξ_2 direction
H1 = distance in meters in the ξ_1 direction at center of grid element
H2 = distance in meters in the ξ_2 direction at center of grid element
H = average depth of grid element in meters (at mean water level)
= MLW + tidal amplitude
ANG = angle in degrees between east and ξ_1 direction measured in a counter-clockwise direction
YGRID = latitude of grid center in degrees (positive for northern hemisphere) to compute the Coriolis parameter
XGRID = longitude of grid center in degrees (Note: model does not use this. Only used for postprocessing purposes)
DATUM = datum of grid element in meters (above some reference elevation)

NOTE: Total number of wet grid ≤ total number of grid elements. Grid information need be specified for wet points only and it is not necessary to specify grid information for other grid elements. H must be sufficiently large in order to remain wet at low tide.

Table 10-1B: model_grid data format

Data Group D: Specification of Thin Dams

1. Comment

80
COM
80A1

COM = user specified comment for thin dams.

2. Number of Thin Dams

5
NUMTDAM
(I5)

NOTE: If there is no thin dam specified in the model domain, user can either specify NUMTDAM = 0 or skip Data Group D.

2. Location of Thin Dams

5	10	15	20
ISTDAM(N)	JSTDAM(N)	DIRTDAM(N)	NTDAM(N)
2I5, 1X, A4, I5			

ISTDAM(N) = I number of grid element in which thin dam begins
JSTDAM(N) = j number of grid element in which thin dam begins
DIRTDAM(N) = direction of thin dam (cross-section)
"IDIR" - cross-section is in the ξ_1 direction
"JDIR" - cross-section is in the ξ_2 direction
NTDAM(N) = number of grid elements in the thin dam cross-section

Table 10-1B: model_grid data format

10.2 Initial Condition

The initial condition input file name is "init_tands". There is only one data group. Tables 8-2A and 8-2B describe the data structure and format respectively.

Table 10-2A: Data structure of init_tands

Data Group	Description
A.	Location, Temperature and Salinity at Standard Levels
NOTE:	The init_tands file is only needed if HYDTYPE = "INTERNAL"

Table 10-2B: init_tands data format

Data Group A: Location, Temperature and Salinity at Standard Levels

5	10	15	20	...	260	265	270	...	510
I	J	TS(I,J,1)	TS (I,J,2)	...	TS(I,J,KSL)	SS(I,J,1)	SS(I,J,2)	...	SS(I,J,KSL)

2I5,100F5.0

I = I number of grid element in the ξ_1 direction
J = j number of grid element in the ξ_2 direction
TS = temperature in ^{o}C at each standard level
SS = salinity in psu at each standard level

NOTE: 1. KSL = number of standard levels. To ensure proper interpolation of data from standard level to sigma level, each bottom-most sigma level must be bracketed by two standard levels. These standard levels must contain data.

10.3 Model Simulation Input Data

The name of the input file is run_data. This file contains parameters which control the type and length of the simulation. The frequency of various output is included here. The data also contains various modeling contents. There are eight data groups as listed in Tables 8-3A and 8-3B.

Table 10-3A. Data structure of run_data

Data Group	Description
A.	Run Computational, Output and Print Characteristics
	Comment
	Comment-Run options
	Run options
	Comment-Run computational characteristics
	Run computational characteristics
	Comment-Run output characteristics
	Run output characteristics
	Comment-Run print characteristics
	Run print characteristics
B.	Hydrodynamic Characteristics
	Comment-Constants of the model problem
	Constants of the model problem
	Comment-Horizontal mixing characteristics
	Horizontal mixing characteristics
	Comment-Vertical mixing characteristics
	Vertical mixing characteristics
C.	Result Evaluation
	Computational history for plotting
	Comment
	Number and averaging interval of computational history output sets
	Time in number of time steps for writing the output
	Averaging interval for skill assessment
	Comment
	Averaging interval
	Computed time series for elevations
	Comment
	Number of grid elements
	Location of grid elements
	Computed time series for currents, temperature, salinity & transport quantities
	Comment
	Number of grid elements
	Location of grid elements
	Computed time series for cross sectional fluxes
	Comment
	Number of cross sections
	Location of cross sections
	Computational results for water quality

Table 10-3A. Data structure of run_data

Data Group	Description
	Comment
	Number and averaging interval of computational result output sets
	Time in number of time steps for writing the output
D.	Standard Level Declaration
	Comment
	Number of standard levels
	Standard levels
E.	Initial Temperature and Salinity Data
	Comment
	Initial temperature and salinity data option
	Initial temperature data
	Initial salinity data
F.	Open Boundary Condition Information
	Elevation boundary conditions
	Comment
	Number of grid elements and option
	Elevation boundary conditions
Option 1	Time variable data
	Location of grid elements
	Time of observation
	Elevation data
Option 2	Computer generated data from tidal constituents
	Location of grid elements and mean water level
	Amplitudes of the 6 dominant harmonic constituents
	Phases of the 6 dominant harmonic constituents
	Time Variable temperature and salinity boundary conditions
	Comment
	Temperature and salinity boundary conditions
	Time of observation
	Location of grid elements, temperature and salinity data
G.	Discharge Information
	Time variable river/dam and onshore intake/outfall discharges
	Comment
	Number of grid elements
	Location of grid elements/vertical distribution of intake/outfall discharge
	Time of observation
	Discharge data
	Temperature data
	Salinity data
	Time variable offshore intake/outfall (diffuser) discharges
	Comment
	Number of grid elements
	Location of grid elements/vertical distribution of intake/outfall diffuser discharge

Table 10-3A. Data structure of run_data

Data Group	Description
	Time of observation
	Discharge data
	Temperature data
	Salinity data
	Time variable offshore intake/outfall (diffuser) discharges in loops
	Comment
	Number of grid elements
	Location of grid elements/vertical distribution of intake/outfall diffuser discharge
	Time of observation
	Discharge data
	Temperature data
	Time variable offshore intake/outfall discharges in loops
	Comment
	Grid elements (I,J) and distribution of flows
	Discharge data
	Temperature data
	Salinity data
H.	Meteorological Data
	Comment
	Meteorological data option
	Meteorological data
Option 1	Time variable surface heat data, salt flux data and wind data
	Time of observation
	Precipitation, evaporation, heat flux, wind speed and direction data
Option 2	Synoptic time variable surface heat flux data and synoptic wind and atmospheric pressure data
	Wind and pressure data input from file “synop_wind”
	Surface heat flux data input from file “synop_hflx”
Option 3	Time variable surface heat flux parameters, salt flux data and wind data
	Time of observation
	Precipitation, evaporation, heat flux, wind speed and direction data

Table 10-3B: Data format of run_data

DATA GROUP A: **Computational and Output Characteristics**

1. Comment

80
COM

80A1

COM = user specified comment for run information

2. Comment - Run Options

80
COM

80A1

COM = user specified header for run options

3. Run Options

10	20	30	40	50	60	70
HYDTYPE	WAVEDYN	TRACER	SEDTRAN	CHEMTRAN	SEDTYPE	PARTICLE

2X,A8,2X,A8,3X,A7,3X,A7,3X,A7,6X,A4,3X,A7

HYDTYPE = "INTERNAL" - use internal (ECOM) hydrodynamics
= "EXTERNAL" - use external hydrodynamics input from 'hqi_tran' file

WAVEDYN = "NEGLECT " - no effect of surface waves on bottom friction
= "SMBMODEL" - include effects of waves on bottom friction, internal calculation of waves using SMB theory
= "DONMODEL" - include effects of waves on bottom friction, internal calculation of waves using Donelan Theory
= "EXTERNAL" - include effects of waves on bottom friction, wave parameters input from 'wave_input' file, (external calculation using WAM or HISWA)

TRACER = "INCLUDE" - dissolved tracer transport will be simulated
= "NEGLECT" - no simulation of dissolved tracer transport

SEDTRAN = "INCLUDE" - sediment transport will be simulated
= "NEGLECT" - no simulation of sediment transport

CHEMTRAN = "INCLUDE" - sediment-bound tracer transport will be simulated
= "NEGLECT" - no simulation of sediment-bound transport

SEDTYPE = "BOTH" - cohesive and non-cohesive sediment transport
= "MUD " - cohesive sediment transport only
= "SAND" - non-cohesive sediment transport only
PARTICLE = "INCLUDE" - particle tracking will be simulated
= "NEGLECT" - no simulation of particle tracking

NOTE: SMBMODEL is not fully operational.

NOTE: CHEMTRAN = "INCLUDE" requires that SEDTRAN = "INCLUDE".

NOTE: CHEMTRAN option is not fully operational.

4. Comment - Run Computational Characteristics

80
COM
80A1

COM = user specified header to identify run computational characteristics

5. Run Computational Characteristics

10	15	20	25	30	35	40	45	50	60	70	75
DTI	ISPLIT	IRAMP	IYR	IMO	IDA	IHR	NHYD	SGW	WETEPS	WETMIN	TUNIT

A10,I5,F5.0,5I5,F5.0,2F10.0,A5

DTI = time step in seconds of the internal model (the maximum allowable time step in seconds can be found in "gcmprt" file) or VARI (user specifies the time steps to be used in "timestep.inp" file)
ISPLIT = number of time steps between the internal and external modes. Please refer to Section 8.1 for more details.
NOTE: If TOR = "PROGNOSTIC" or "DIAGNOSTIC", ISPLIT >3
IRAMP = number of time steps over which all model forcing functions are ramped from zero to their full values linearly
IYR, IMO, IDA, IHR = year, month, day, hour of model start time and IYR should be a 4-digit number
NHYD = number of time steps between each hydrodynamic transport field input from "hqi_tran", only used if HYDTYPE = "EXTERNAL"
SGW = semi-prognostic coefficient based on Sheng, Greatbatch and Wang (2001). Please see Section 8-4 for details. If SGW = 1 and TOR = "PROGNOSTIC," the model will be in full prognostic mode (Default = 1.0)
WETEPS = water elevation differences between dry cell and wet cell to determine connection from wet cell to dry cell (unit: meter). When the water elevation of the wet grid cell is higher than WETPES, then the adjoining cell will be flooded. Recommended value: 0.1 m or higher.
WETMIN = minimum water elevation retained in the drying cell (unit: meter).

Table 10-3B: Data format of run_data

Recommended value: 0.3 m or higher.

TUNIT = time unit for NSTEPS, IRAMP, IPRINT, IPRTSTART. TUNIT can be "DAY", " ", or "NDTI", if no option is specified, model assumes "NDTI" as TUNIT

6. Comment - Run Output Characteristics

80
COM
80A1

COM = user specified header to identify NSTEPS, IPRINT, IPRTSTART, RESTAR, TOR, ADVECT output characteristics

7. Run Output Characteristics

10	20	30	41	52	63	74	83
NSTEPS	IPRINT	IPRTSTART	RESTART	TOR	ADVECT	SCHEME	SEDRESTART
3I10,1X,A10,1X,A10,1X,A10,1X,A10,1X,A8							

NSTEPS = run duration specified in TUNIT. If TUNIT is "DAY", NSTEPS is run duration in days

IPRINT = print interval in number of time steps

IPRTSTART = time in number of time steps at which printing will begin

RESTAR = "COLD START" - all initial conditions are set to zero
= "HOT START" - all initial conditions are input from file "restart"

TOR = "BAROTROPIC" - 2-D calculation (bottom stress calculated in ADVAVE)
= "PROGNOSTIC" - 3-D calculation (bottom stress calculated in PROFU & PROFV)
= "DIAGNOSTIC" - 3-D calculation with temperature and salinity held fixed
= "TEMP-ONLY" - 3-D prognostic run while initial salinity values are held throughout the simulation
= SALT-ONLY" - 3-D prognostic run while initial temperature fields are held throughout the simulation

ADVECT = "LINEAR" - no momentum advection terms
= "NON-LINEAR" - include momentum advection terms

SCHEME = "CENTRAL" - central finite difference scheme for advection
= "UPWIND" - upwind finite difference scheme for advection
= "SMOLAR_R" - finite difference scheme due to Smolarkiewicz and using reclusive formulation for antidiffusive velocities
= "SMOLAR_2" - finite difference scheme due to Smolarkiewicz and using two passes for corrections of numerical diffusion

SEDRESTART = "COLDSEDS" - sediment bed initialized using the "core_field.sdf" file
= "WARMSEDS" - sediment bed initialized using the

Table 10-3B: Data format of run_data

"SEDRESTARTFILE" file.

NOTE: If RESTAR = "HOT START", then the user should move or copy "startup" to "restart" before the model run. "startup" is a file containing computed results from the previous model run.
If TOR = "BAROTROPIC", ISPLIT = 1
If TOR = "PROGNOSTIC" or "DIAGNOSTIC", ISPLIT >3

NOTE: HOT START option is not fully operational for Particle Tracking and wave simulations.

8. Comment - Run Print Characteristics

80
COM

80A1

COM = user specified header to identify run print characteristics of variables DEV, VSX, JROW, VSY, IROW, U, V, W, AM, S, T, RHO, Q2, L, KM, KH for output to "gcmprt"and netCDF output

9. Run Print Characteristics

5	10	15	20	25	30	35	40
DEV	VSX	JROW	VSY	ICOL	U	V	W

45	50	55	60	65	70	75	80
AM	S	T	RHO	Q2	L	KM	KH

2X,A3,4X,A1,I5,4X,A1,I5,11(4X,A1)

DEV = primary output device for viewing "gcmprt"
= "SCR" - for 15 columns across the page, suitable for printing on a screen with no wrap around
= "LPR" - for 25 columns across the page, suitable for printing on a laser or line printer

VSX = vertical slice in the x (ξ_1) direction of various model quantities included in the "gcmprt" file
= "Y" - vertical slices
= "N" - no vertical slices

JROW = j number at which the vertical slice in the x (ξ_1) direction will be taken
= 0, for VSX="N"

VSY = vertical slice in the y (ξ_2) direction of various model quantities included in

Table 10-3B: Data format of run_data

		the "gcmprt" file
	=	"Y" - vertical slices
	=	"N" - no vertical slices
ICOL	=	I number at which the vertical slice in the y (ξ_2) direction will be taken
	=	0, for VSY="N"
U	=	U velocity included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
V	=	V velocity included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
W	=	W velocity included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
AM	=	horizontal mixing included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
S	=	salinity and conservative tracer included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
T	=	temperature included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
RHO	=	density included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
Q2	=	turbulent kinetic energy included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit
L	=	mixing length included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit
KM	=	mixing K_M included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit
KH	=	mixing K_H included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit

Table 10-3B: Data format of run_data

DATA GROUP B: **Hydrodynamic Characteristics**

1. Comment - Constants of the Model Problem

80
COM

80A1

COM = user specified header for BFRIC, ZOB, NU, ALPHA, TLAG constants

2. Constants of the Model Problem

10	20	30	40	50	60	70	80
BFRIC	ZOB	NU	THETA	ALPHA	TLAG	NWAVE	BCTYPE

6E10.3, I10, 3x,A7

BFRIC = minimum bottom friction coefficient (non-dimensional)
If user wants to specify spatially variable (2D) bottom friction coefficients, specify BFRIC as "VARI" (6X, A4) and provide "bfric2d.inp" file. Please refer to Table 10-26 for more details of format specification of "bfric2d.inp" file.

ZOB = bottom roughness coefficient in meters

NU = coefficient in time filter (non-dimensional)
= 0.1 (recommended value)

THETA = weighting factor (0-1); 0 - explicit and 1- implicit scheme
= 0.225 (recommended value)

ALPHA = advection time scale for temperature and salinity at the boundary time "HOURS" over which the boundary values reach their full specified value during the flood cycle from the values exiting at the end of the ebb cycle. *Caution: If the user does not want boundary relaxation (α-folding), specify ALPHA = 0.

TLAG = friction time scale (Hours) for barotropic radiation boundary condition (only needed if user selects BCTYPE as PCLAMP

NWAVE = number of time steps between each update of bottom friction coefficient, only used if WAVEHYD is not "NEGLECT"

BCTYPE = baratropic radiation boundary condition types
"CLAMPED" - clamp boundary condition (no radiation)
"PCLAMP" - partially clamped. Note: if user selects PCLAMP type B.C., user must provide TLAG in Hours
"OCLAMP" - optimized clamp which is same as RANDB except λt is non unity.
"RANDB" - Reid and Bodine type boundary condition
"IRANDB" - inverted Reid and Bodine type boundary condition)(λ_τ = 1)

Table 10-3B: Data format of run_data

3. Comment - Horizontal Mixing Characteristics

80
COM

80A1

COM = user specified header for HORZMIX, HORCON, HPRNU mixing characteristics

4. Horizontal Mixing Characteristics

10	20	30
HORZMIX	HORCON	HPRNU

A10,2E10.3

HORZMIX = "CONSTANT" - value given for HORCON is scaled in each grid element relative to the smallest grid element
= "CLOSURE" - value given for HORCON is used in Smagorinsky's formula for mixing

HORCON = value used as a constant or in Smagorinsky's formula based on HORZMIX (non-dimensional)
If user wants to specify spatially variable (2D) HORCON, specify HORCON as "VARI" (6X,A4) and provide "horcon2d.inp" file. Please refer to Table 10-25 for more details of format specification of "horcon2d.inp" file.

HPRNU = horizontal Prandtl number - ratio of horizontal viscosity to horizontal diffusivity (momentum mixing/dispersive mixing)
= 1.0 (recommended value)

5. Comment - Vertical Mixing Characteristics

80
COM

80A1

COM = user specified header for VERTMIX, UMOL, VPRNU mixing characteristics

6. Vertical Mixing Characteristics

10	20	30	40
VERTMIX	UMOL	VPRNU	BETA

A10,3E10.3 or A10,6X,A4,2E10.3 if umol is spatially variable

VERTMIX = "CONSTANT" - value given for UMOL applies everywhere
= "CLOSURE" - value given to UMOL is background mixing
= "EMPIRICAL" - empirical vertical turbulent mixing based on Kent and

Pritchard (1959) and Offcer (1976)

UMOL = constant or background mixing in m^2/sec
= 1.0E-06 (recommended value if VERTMIX = "CLOSURE") or "EMPIRICAL".
If user wants to specify spatially variable (2D) UMOL, specify UMOL as "VARI" (6X.A4) and provide "umol2d.inp" file. Please refer to table 10-27 for more details of format specification of "umol2d.inp" file

VPRNU = vertical Prandtl number - ratio of vertical viscosity to vertical diffusivity (momentum mixing/diffusive mixing) for VERTMIX = "CONSTANT"
= If VERTMIX = "EMPIRICAL", VPRNU acts as coefficient α in the empirical mixing equation (8-9a)

BETA = Coefficient β in the empirical mixing equation (8-8 and 8-9) if VERTMIX = "EMPIRICAL". For other VERTMIX options, BETA will be ignored.
= 1.0 (recommended value)

DATA GROUP C: Result Evaluation

1. Computational History Output for Plotting

a. Comment

80
COM
80A1

COM = user specified comment for computational history output

b. Number and Averaging Interval of Computational History Output Sets

10	20	30	40	45	50
JHM	AVGE	IPLTFORM	PLTZERO	OPTAVG	OUTFORM
I10, F10.3, 65X,A4, F10.2, 1X, A4,2X,A3					

JHM = number of times all information necessary for plotting will be written in "gcmplt" and "part_location" (if PARTICLE = "INCLUDE")

AVGE = interval in number of time steps or hours for averaging the elevations, temperature, salinity and currents for all grid elements

IPLTFORM = "USER" or "(left in blank spaces") user specifies the "gcmplt" output intervals.
"AUTO" output interval will be generated by ECOMSED based on the values of PLTZERO, AVGE and JHM

PLTZERO = The beginning timestep or hour of "gcmplt" output (TZERO)

OPTAVG = indicating the units of AVGE and PLTZERO. "HOUR": time control is in hour,
"NDTI": time control is in number of timesteps.
If the OPTAVG is in hour and AVGE is not an integer multiple of timestep ECOMSED will stop and ask for another AVGE period.

Table 10-3B: Data format of run_data

OUTFORM = Output format of "gcmplt" file.
"BIN": Binary output format
"CDF": netCDF output format
If OUTFORM = "CDF", please refer to Data Group A.9 for the selection of output parameters.

NOTE: If JHM = 0 or IPLTFORM = "AUTO", then go to Data Group C.2 (Averaging Interval for Skill Assessment)

c. Time in Number of Time Steps for Writing the Output

8	16	...	80
IHIST(1)	IHIST(2)	...	IHIST(JHM)

10I8

IHIST = time in number of time steps all information will be written in "gcmplt" and "part_location" (for particle tracking output when PARTICLE = "INCLUDE")

NOTE: IHIST relative to start of run (independent of RESTART option specified)

2. Averaging Interval for Skill Assessment

a. Comment

80
COM

80A1

COM = user specified comment for averaging interval for skill assessment

b. Averaging Interval

10
ISKILL

I10

ISKILL = interval in number of time steps for averaging the elevations, temperature, salinity and currents and cross sectional fluxes for user specified grid elements (for example, at the tide gauge locations)
= 0, no element stored in "gcmtsr" for skill assessment

NOTE: If ISKILL=0, then go to Data Group C.6 (Computational Results for Water Quality Model)

Table 10-3B: Data format of run_data

3. Computed Time Series for Elevations

a. Comment

80
COM
80A1

COM = user specified comment for computed time series for elevations

b. Number of Grid Elements

5
EPTS
I5

EPTS = number of grid elements for which time series of elevations are to be stored in "gcmtsr"

NOTE: If EPTS=0, then go to Data Group C.4 (Computed Time Series for Currents, Temperature and Salinity)

c. Location of Grid Elements

5	10	...	75	80
INXIE(1)	INXJE(1)	...	INXIE(EPTS)	INXJE(EPTS)
16I5				

INXIE = I number of grid element
INXJE = j number of grid element

4. Computed Time Series for Currents, Temperature, Salinity and Transport Quantities

a. Comment

80
COM
80A1

COM = user specified comment for computed time series for temperature, salinity and currents

b. Number of Grid Elements

5
VPTS
I5

Table 10-3B: Data format of run_data

VPTS = number of grid elements for which time series of temperature, salinity and currents are to be stored in "gcmtsr"

NOTE: If VPTS=0, then go to Data Group C.5 (Computed Time Series for Cross Sectional Fluxes)

c. Location of Grid Elements

5	10	...	75	80
INXIV(1)	INXJV(1)	...	INXIV(VPTS)	INXJV(VPTS)

16I5

INXIV = I number of grid element
INXJV = j number of grid element

5. Computed Time Series for Cross Sectional Fluxes

a. Comment

80
COM

80A1

COM = user specified comment for computed time series for cross sectional fluxes

b. Number of Cross Sections

5
FPTS

I5

FPTS = number of cross sections for which time series of fluxes are to be stored in "gcmtsr"

NOTE: If FPTS=0, then go to Data Group C.6 (Computation Results for Water Quality Model)

Table 10-3B: Data format of run_data

c. Location of Cross Sections

5	10	15	20	...
ISFLX(1)	JSFLX(1)	DIRFLX(1)	NFLXE(1)	...

4(2I5,1X,A4,I5)

65	70	75	80
ISFLX(FPTS)	JSFLX(FPTS)	DIRFLX(FPTS)	NFLXE(FPTS)

ISFLX = I number of grid element in which cross section begins
JSFLX = j number of grid element in which cross section begins
DIRFLX = direction of cross-section
= "IDIR" - cross-section is in the ξ_1 direction
= "JDIR" - cross-section is in the ξ_2 direction
NFLXE = number of grid elements in the cross-section

6. Computation Results for Water Quality Model

a. Comment

80
COM

80A1

COM = user specified comment for computation results for water quality model

b. Number and Averaging Interval of Computation Result Output Sets

10	20	30	40	50
JTM	NPLPF	ITRNFORM	IZERO	IWET

5I10

JTM = number of times all information necessary for the water quality model input is generated
NPLPF = interval in number of time steps for averaging the elevations and currents to be used as input in the water quality model
ITRNFORM = 0 : user specified time steps for writing the output
1: ECOM will generate the writing block (i.e. section 6.c.)
IZERO = # of time steps to skip before start to writing 'gcm_tran' information. IZERO should not be '0' if 'COLD START'. If ITRNFORM = 0, IZERO will be ignored.
IWET = 0 : entire grid output
1 : wet grid only output

Table 10-3B: Data format of run_data

NOTE: If JTM = 0, then go to Data Group D (Standard Level Declaration)

c. Time in Number of Time Steps for Writing the Output

IF ITRANFORM = 0
IF ITRANFORM = 1 skip this block

8	16	...	80
ITRAC(1)	ITRAC(2)	...	ITRAC(JTM)
10I8			

ITRAC = time in number of time steps at which the information will be output, necessary for water quality model input

NOTE: ITRAC relative to start of run (independent of RESTART option specified)

DATA GROUP D: Standard Level Declaration

1. Comment

80
COM
80A1

COM = user specified comment about the standard levels

2. Number of Standard Levels

5
IKSL
I5

IKSL = number of standard levels (< 50)

NOTE: To reduce the amount of computer storage required, keep the number of standard levels (IKSL) at a minimum, i.e., IKSL < 50.

Table 10-3B: Data format of run_data

3. Standard Levels

10	20	...	80
DPTHSL(1)	DPTHSL(2)	...	DPTHSL(IKSL)

8F10.5

DPTHSL = depth of standard level in meters with respect to surface water level

NOTE: It is not necessary to include the surface level, although it may be included. If not, constituent values associated with the first level below the surface will be applied to the depth between the surface and the first standard level. Extrapolation to the surface may cause incorrect representation of the vertical profile. To ensure proper interpolation of data from standard level to sigma level, each bottom-most sigma level must be bracketed by two standard levels. These standard levels must contain data.

DATA GROUP E: Initial Temperature and Salinity

1. Comment

80
COM

80A1

COM = user specified comment for temperature and salinity data

2. Initial Temperature and Salinity Data Option

10
OPTTSI

A5

OPTTSI = "FIXED" - initial temperature and salinity data are constant for each standard level.

= "DATA" - initial temperature and salinity data vary horizontally and vertically - data read in from data file "init_tands".

If OPTTSI = "DATA", then go to Data Group F (Open Boundary Condition Information)

3. Initial Temperature Data

10	20	30	...	80
TSI(1)	TSI(2)	TSI(3)	...	TSI(IKSL)

8F10.5

Table 10-3B: Data format of run_data

TSI = temperature in °C

4. Initial Salinity Data

10	20	30	...	80
SSI(1)	SSI(2)	SSI(3)	...	SSI(IKSL)
8F10.5				

SSI = salinity in psu

NOTE: IKSL = number of standard levels

DATA GROUP F: Open Boundary Condition Information

1. **Elevation Boundary Conditions**

a. Comment

80
COM
80A1

COM = user specified comment for elevation boundary condition

b. Number of Grid Elements and Option

5	26
NUMEBC	OPTEBC
I5,1X,A20	

NUMEBC = total number of elevation boundary grid elements. If NUMEBC = 0, then go to Data Group G (Discharge Information)

OPTEBC = "DATA" - use Elevation Boundary Conditions OPTION 1 - Time Variable Data

= "TIDAL CONSTITUENT" - use Elevation Boundary Conditions OPTION 2 - Computer Generated Data from Tidal Constituents

c. Elevation Boundary Conditions

OPTION 1 - TIME VARIABLE DATA

I. Location of Grid Elements

Table 10-3B: Data format of run_data

5	10	15	20	...
IETA(1)	JETA(1)	ICON(1)	JCON(1)	...

16I5

65	70	75	80
IETA(NUMEBC)	JETA(NUMEBC)	ICON(NUMEBC)	JCON(NUMEBC)

IETA = I number of grid element where elevation is specified
JETA = j number of grid element where elevation is specified
ICON = I number of connecting grid element (nearest interior non- boundary grid element)
JCON = j number of connecting grid element (nearest interior non- boundary grid element)

NOTE: Every boundary element should have a connecting interior grid element.

ii. Time of Observation

10
TIME

F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

iii. Elevation Data

10	20	30	...	80
EBDRY(1)	EBDRY(2)	EBDRY(3)	...	EBDRY(NUMEBC)

8F10.5

EBDRY = boundary elevation data in meters at time "TIME"

NOTE: Sequence (TIME/EBDRY) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-3B: Data format of run_data

OPTION 2 - COMPUTER GENERATED DATA FROM TIDAL CONSTITUENTS

I. Location of Grid Elements and Mean Water Level

5	10	15	20	30
IETA	JETA	ICON	JCON	EMEAN

4I5,F10.5

IETA = I number of grid element
JETA = j number of grid element
ICON = I number of connecting grid element (nearest interior non- boundary grid element)
JCON = j number of connecting grid element (nearest interior non- boundary grid element)
EMEAN = mean water level in meters with reference to the lowest mean water level of entire domain

ii. Amplitudes of the 6 Dominant Harmonic Constituents

10	20	30	40	50	60
AMP-S_2	AMP-M_2	AMP-N_2	AMP-K_1	AMP-P_1	AMP-O_1

6F10.5

AMP-S_2 = solar semidiurnal amplitude in meters (period = 12.00 hr)
AMP-M_2 = lunar semidiurnal amplitude in meters (period = 12.42 hr)
AMP-N_2 = lunar semidiurnal amplitude in meters (period = 12.66 hr)
AMP-K_1 = lunar diurnal declination amplitude in meters (period = 23.94 hr)
AMP-P_1 = solar diurnal declination amplitude in meters (period = 24.06 hr)
AMP-O_1 = lunar diurnal declination amplitude in meters (period = 25.82 hr)

iii. Phases of the 6 Dominant Harmonic Constituents

10	20	30	40	50	60
PHASE-S_2	PHASE-M_2	PHASE-N_2	PHASE-K_1	PHASE-P_1	PHASE-O_1

6F10.5

PHASE-S_2 = solar semidiurnal phase in degrees (period = 12.00 hr)
PHASE-M_2 = lunar semidiurnal phase in degrees (period = 12.42 hr)
PHASE-N_2 = lunar semidiurnal phase in degrees (period = 12.66 hr)
PHASE-K_1 = lunar diurnal declination phase in degrees (period = 23.94 hr)
PHASE-P_1 = solar diurnal declination phase in degrees (period = 24.06 hr)
PHASE-O_1 = lunar diurnal declination phase in degrees (period = 25.82 hr)

NOTE: Every boundary element should have a connecting interior grid element. Sequence i/ii/iii repeated for each boundary element. Total number = NUMEBC (total number of elevation boundary grid elements). Phases of each component are in degrees and are with respect to Greenwich Mean Time.

Table 10-3B: Data format of run_data

2. Time Variable Temperature and Salinity Boundary Conditions

a. Comment

80
COM
80A1

COM = user specified comment for temperature and salinity boundary conditions

b. Temperature and Salinity Boundary Conditions

i. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

ii. Location of Grid Elements, Temperature and Salinity Data

5	10	15	20	...
ITAS	JTAS	TBDRYSL(NUMEBC,1)	TBDRYSL(NUMEBC,2)	...
2I5,100F5.0				

260	265	270	...
TBDRSYL(NUMEBC,IKSL)	SBDRYSL(NUMEBC,1)	SBDRYSL(NUMEBC,2)	...

510
SBDRYSL(NUMEBC,IKSL)

ITAS = i number of grid element where temperature and salinity are specified
JTAS = j number of grid element where temperature and salinity are specified
TBDRYSL = temperature in °C at time "TIME" for each standard level (not sigma level)
SBDRYSL = salinity in psu at time "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ITAS/JTAS/TBDRYSL/SBDRYSL) repeated for each location. Total number = NUMEBC (total number of boundary grid elements). The sequence (TIME/ TBDRYSL/SBDRYSL) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. TIME for

Table 10-3B: Data format of run_data

temperature and salinity observation need not be the same as for elevation observations.

2. The ITAS, JTAS sequence of temperature/salinity boundary conditions must correspond exactly to the IETA, JETA sequence of elevation boundary conditions, i.e., ITAS = IETA and JTAS = JETA for n = 1 to n = NUMEBC.

Table 10-3B: Data format of run_data

DATA GROUP G: Discharge Information

1. Time Variable River/Dam and Onshore Intake/Outfall Discharges

a. Comment

80
COM
80A1

COM = user specified comment for discharge

b. Number of Grid Elements

5
NUMQBC
I5

NUMQBC = total number of discharge boundary grid elements. If NUMQBC = 0, then go to Data Group G.2 (Time Variable Offshore Intake/Outfall (Diffuser) Discharges)

c. Location of Grid Elements/Vertical Distribution of Intake/Outfall Discharge

5	10	15	20
IQD(NUMQBC)	JQD(NUMQBC)	IQC(NUMQBC)	JQC(NUMQBC)
4I5,20F5.0			

25	30	35	...	120
VQDIST(1)	VQDIST(2)	VQDIST(3)	...	VQDIST(KBM1)

IQD = i number of grid element discharge enters/leaves
JQD = j number of grid element discharge enters/leaves
IQC = i number of connecting exterior boundary grid element
JQC = j number of connecting exterior boundary grid element
VQDIST = percentage (not fraction) of total discharge QDIS apportioned to each model layer from surface to bottom at location (IQD,JQD)
KBMI = KB-1

NOTE: 1. Sequence (IQD/JQD/IQC/JQC/VQDIST) is repeated for each discharge location.

Table 10-3B: Data format of run_data

d. Time of Observation

10
TIME

F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

e. Discharge Data

10	20	30	...	80
QDIS(1)	QDIS(2)	QDIS(3)	...	QDIS(NUMQBC)

8F10.5

QDIS = discharge flow in m^3/sec
> 0.0 (positive) for flow into the model domain (river/outfall)
< 0.0 (negative) for flow out of the model domain (intake)

f. Temperature Data

10	20	30	...	80
TDIS(1)	TDIS(2)	TDIS(3)	...	TDIS(NUMQBC)

8F10.5

TDIS = temperature of discharge in °C

g. Salinity Data

10	20	30	...	80
SDIS(1)	SDIS(2)	SDIS(3)	...	SDIS(NUMQBC)

8F10.5

SDIS = salinity of discharge in psu

NOTE: Sequence (TIME/QDIS/TDIS/SDIS) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the model domain (intakes) do not require associated T and S values. However, a value of zero should be input as

Table 10-3B: Data format of run_data

the values for T and S of these discharges.

2. Time Variable Offshore Intake/Outfall (Diffuser) Discharges

a. Comment

80
COM
80A1

COM = user specified comment for discharge

b. Number of Grid Elements

5
NUMDBC1
I5

NUMDBC 1 = total number of discharge grid elements. If NUMDBC = 0, then go to Data Group G3 (Time Variable Offshore Intake/Outfall (Diffuser) Discharges in Loops)

c. Location of Grid Elements/Vertical Distribution of Intake/Outfall Diffuser Discharge

5	10	15	20	...	110
IDD(NUMDBC)	JDD(NUMDBC)	VDDIST(1)	VDDIST(2)	...	VDIST(KBM1)
2I5,20F5.0					

IDD = i number of grid element diffuser enters/leaves
JDD = j number of grid element diffuser enters/leaves
VDDIST = percentage (not fraction) of total discharge DQDIFF apportioned each model layer from surface to bottom at location (IDD,JDD)
KBM1 = KB-1

NOTE: 1. Sequence (IDD/JDD/VDDIST) is repeated for each diffuser location.

2. More than one diffuser can be specified at the same location (IDD, JDD)

d. Time of Observation

10
TIME
F10.5

Table 10-3B: Data format of run_data

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

e. Discharge Data

10	20	...	80
QDIFF(1)	QDIFF(2)	...	QDIFF(NUMDBC1)

8F10.5

QDIFF = diffuser discharge in m^3/sec

f. Temperature Data

10	20	30	...	80
TDIFF(1)	TDIFF(2)	TDIFF(3)	...	TDIFF(NUMDBC)

8F10.5

TDIFF = temperature of diffuser discharge in ^oC

g. Salinity Data

10	20	30	...	80
SDIFF(1)	SDIFF(2)	SDIFF(3)	...	SDIFF(NUMDBC)

8F10.5

SDIFF = salinity of diffuser discharge in psu

NOTE: Sequence (TIME/QDIFF/TDIFF/SDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the model domain do not require associated T and S values. However, a value of zero should be input as the values for T and S of these discharges.

3. Time Variable Offshore Intake/Outfall (Diffuser) Discharges in Loops

a. Comment

80
COM
80A1

COM = user specified comment for discharge in loops

Table 10-3B: Data format of run_data

b. Number of Grid Elements

5
NUMDBC2
I5

NUMDBC2 = total number of discharge grid elements. If NUMDBC2 = 0, then go to Data Group H (Meteorological Data). The NUMDBC2 should be even numbers; intake/outfall diffusers are specified in pairs; diffuser is intake and the other is recirculating discharging outfall (i.e., one diffuser discharges the volume of water withdrawn through the other)

c. Location of Grid Elements/Vertical Distribution of Intake/Outfall Diffuser Discharge

5	10	15	20	...	110
IDD(NUMDBC)	JDD(NUMDBC)	VDDIST(1)	VDDIST(2)	...	VDIST(KBM1)
2I5,20F5.0					

IDD = i number of grid element diffuser enters/leaves
JDD = j number of grid element diffuser enters/leaves
VDDIST = percentage (not fraction) of total discharge DQDIFF apportioned each model layer from surface to bottom at location (IDD,JDD)
KBM1 = KB-1

NOTE: Sequence (IDD/JDD/VDDIST) is repeated for each intake/outfall diffuser location.

d. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

e. Discharge Data

10	20	...	80
DQDIFF(1)	DQDIFF(2)	...	DQDIFF(NUMDBC2)
8F10.5			

Table 10-3B: Data format of run_data

DQDIFF = diffuser discharge in m^3/sec. Even though DQDIFF(N) and DQDIFF(N+1) is a coupling intake/outfall pair, the DQDIFF(N) and DQDIFF(N+1) need not be equal.

f. Temperature Data

10	20	30	...	80
DTDIFF(1)	DTDIFF(2)	DTDIFF(3)	...	DTDIFF(NUMDBC2)

8F10.5

DTDIFF = temperature increase/decrease of diffuser discharge in °C. Only effective on diffuser having positive values of DQDIFF. This increase/decrease of temperature is with respect to the temperature of corresponding intake.

g. Salinity Data

10	20	30	...	80
DSDIFF(1)	DSDIFF(2)	DSDIFF(3)	...	DSDIFF(NUMDBC2)

8F10.5

DSDIFF = salinity increase/decrease of diffuser discharge in psu. Only effective on diffuser having positive values of DQDIFF.

NOTE: Sequence (TIME/DQDIFF/DTDIFF/DSDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the model domain do not require associated T and S values. However, a value of zero should be input as the values for T and S of these discharges.

Table 10-3B: Data format of run_data

DATA GROUP H: Meteorological Data

1. Comment

80
COM

80A1

COM = user specified comment for meteorological data

2. Meteorological Data Option

10	20	30	40	50	60	70
OPTMBC	ALAT	ALON	TR	WNDSH	REFL	OPTEXTC

A10,5F10.2, 6X,A4

OPTMBC = "AVERAGED" - a single value for each meteorological parameter is used for all grid element at each time - use Meteorological Data OPTION 1 - Time Variable Surface Heat Flux Data, Salt Flux Data and Wind Data

= "SYNOPTIC" - spatially varying meteorological parameter values are specified for every grid element at each time - use Meteorological Data OPTION 2 - Averaged Time Variable Surface Heat Flux Data and Salt Flux Data and Synoptic Time Variable Wind and Atmospheric Pressure Data

= "AANDBFLX" - heat flux sub-model based on the work of Ahsan and Blumberg (1999). The local heat flux is determined from local surface temperature - use Meteorological Data OPTION 3 - Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data

= "LANDPFLX" - heat flux sub-model based on the work of Large and Pond (1982). The local heat flux is determined from local surface temperature - use Meteorological Data OPTION 3 - Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data.

= "RANDMFLX" - heat flux sub-model based on the work of Rosati and Miyakoda (1988). The local heat flux is determined from local surface temperature - use Meteorological Data OPTION 3 - Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data.

= "SYNOPANB", "SYNOPLNP", "SYNOPRNM": These options allow the user to specify spatially varying wind data along with heat flux sub-model options "AANDBFLX", "LANDPFLX" , and "RANDBFLX", respectively.

ALAT = Latitude (in degrees, median of modeling domain)

ALON = Longitude (in degrees, median of modeling domain) (0 ~ -180 for western hemisphere)

TR = Fraction of short wave radiation absorbed in surface layer

WNDSH = Wind sheltering coefficient (default = 1.0)

REFL = Reflection of shortwave radiation at surface (0.0-1.0) (0.0 - nothing

Table 10-3B: Data format of run_data

reflected; 1.0 - complete reflection) 0.1 (recommended value)

OPTEXTC = Option for extinction coefficients. If "VARI", spatially varying extraction coefficients specified in "extc2d.inp" will be used. If OPTEXTC is left in blank or other than "VARI", the model will use time-varying but spatially uniform EXTC specified in OPTION 3 below.

3. Meteorological Data

OPTION 1 - Time Variable Surface Heat Flux Data, Salt Flux Data and Wind Data

i. Time of Observation

10
TIME

F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

ii. Precipitation, Evaporation, Heat Flux, Wind Speed and Direction Data

10	20	30	40	40
WDS	WDD	HFLUX	QPREC	QEVAP

5F10.5

WDS = wind speed in m/sec
WDD = direction of wind in degrees from which the wind blows, measured clockwise from north
HFLUX = heat flux in watts/m^2
> 0, heating of the water
< 0, cooling of the water
QPREC = amount of precipitation in m/year
QEVAP = amount of evaporation in m/year

NOTE: Sequence (TIME/QPREC/QEVAP/HFLUX/ WDS/WDD) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than (IEND + NSTEPS) x DTI/3600 for HOT START runs.

Table 10-3B: Data format of run_data

OPTION 2 - Synoptic Time Variable Surface Heat Flux Data, Synoptic Wind, and Atmospheric Pressure Data

i. Wind and atmospheric pressure data input from file "synop_wind" (Table 8-4A)

ii Surface Heat Flux Data Input from File "synop_hflx" (Table 8-4B)

OPTION 3 - Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data

i. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

ii Precipitation, Evaporation, Heat Flux, Wind Speed and Direction Data

10	20	30	40	50
WDS	WDD	SWOBS	AIRTMP	RELHUM

60	70	80	90	100
BAROP	CLD	EXTC	QPREC	QEVAP

10F10.5

WDS = wind speed in m/sec
WDD = direction of wind in degrees from which the wind blows, measured clockwise from north
SWOBS = observed shortwave radiation in watts/m^2
AIRTMP = air temperature in °C
RELHUM = relative humidity in percent
BAROP = barometric pressure in mbar
CLD = cloud cover fraction (0.0 to 1.0)
EXTC = extinction coefficient
QPREC = amount of precipitation in m/year
QEVAP = amount of evaporation in m/year

Table 10-3B: Data format of run_data

NOTE: Sequence (TIME/QPREC/QEVAP/AIRTMP/RELHUM/BAROP/SWOBS/WDS/WDD) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run) for COLD START runs, and greater than (IEND + NSTPS) x DTI/3600 for HOT START runs.

Table 10-3B: Data format of run_data

Table 10-4A. synop_wind INPUT FILE SUMMARY OF DATA GROUPS

Data Group	Description
A.	Time Variable Synoptic Wind and Atmospheric Pressure Data Time of observation Wind and atmospheric pressure data

synop_wind INPUT FILE (UNFORMATTED)

Data Group A

1. Time

TIME

TIME = time of observation
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

2. Wind and Atmospheric Pressure Data

```
((TX2D(I,J),TY2D(I,J),PATM(I,J),I=1,IM),J=1,JM)
```

TX2D = velocity component in m/sec in the east-west direction
TY2D = velocity component in m/sec in the north-south direction
PATM = atmospheric pressure in mb

NOTE: Sequence (TIME/TX2D/TY2D) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-4B. synop_hflx INPUT FILE SUMMARY OF DATA GROUPS

Data Groups	Description
A.	Time Variable Synoptic Surface Heat Flux Data
	Time of observation Surface heat flux data

synop_hflx INPUT FILE (UNFORMATTED)

Data Group A

1. Time

TIME

TIME = time of observation
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

2. Surface Heat Flux Data

((SHFLX(I,J),I=1,IM),J=1, JM)

SHFLX = surface heat flux in w/m^2

NOTE: Sequence (TIME/SHFLX) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-5. corner_loc INPUT FILE

Table 8-5 lists the format of corner_loc that contains corner locations of grid elements for wind, wave and particle tracking simulations. For transport calculations, user created input files are summarized in Table 8-6. Tables 8-7 through 8-24 list the detailed formats of those files. Model generated output files are summarized in Table 8-25. Tables 8-26 through 8-30 list the detailed format of some selected model output files in Table 8-25.

NOTE: PARTICLE = "INCLUDE"

5	10	20	30
I	J	XCOR(I,J)	YCOR(I,J)

2I5, 2F10.0

I	=	i number of corner location in ζ_1 direction
J	=	j number of corner location in ζ_2 direction
XCOR(I,J)	=	corner location in x-direction (East), in meters
YCOR(I,J)	=	corner location in y-direction (North), in meters

NOTE: Notation convention is XCOR(I,J) = x(i-1/2, j-1/2) and YCOR(I,J) = y(i-1/2, j-1/2) (Lower left hand corner of element)

Table 10-6. Summary of User Created Input Files for Transport Calculations

File	Description
water_tracer.inp	Contains input parameters and boundary condition values for dissolved tracer transport.
coh_sed.inp	Contains input parameters and boundary condition values for cohesive sediment transport.
noncoh_sed.inp	Contains input parameters and boundary condition values for non-cohesive sediment transport.
coh_trace.inp	Contains input parameters and boundary condition values for cohesive sediment-bound tracer transport.
noncoh_trace.inp	Contains input parameters and boundary condition values for non-cohesive sediment-bound tracer transport.
partrack.inp	Contains input parameters for particle tracking.
bed_mask	Contains sediment bed map for the entire model grid.
p0_init	Contains spatially-variable, initial cohesive bed fractions for the entire model grid.
a0_init	Contains spatially-variable a_0 values for the entire model grid.
exp_init	Contains spatially-variable values of exponent n for the entire model grid.
bed_d50	Contains spatially-variable D_{50} values for the entire model grid.
bed_frac.mud	Contains spatially-variable cohesive composition fractions for the entire model grid, clay/silt fraction.
bed_frac.sand	Contains spatially-variable cohesive composition fractions for the entire model grid, sand fraction.
bed_bulkden:	Contains spatially-variable sediment bed bulk density for the entire model grid.
bed_chemic:	Contains spatially-variable initial bed concentrations for sediment-bound tracer for the entire model grid.
NOTE:	All of the above input files are formatted.
hqi_geom:	Contains grid segmentation information to be used for transport calculations.
hqi_tran:	Contains the computed results as a time history for surface elevations and hydrodynamic advection/dispersion fields to be used for transport calculations.
wave_input:	Contains computed results as a time history for wind wave parameters as calculated using a wind wave model (e.g., WAM or HISWA).
NOTE:	These three files are unformatted.

Table 10-7. water_trace.inp INPUT FILE

NOTE: This file must be included for dissolved tracer transport simulations. (TRACER = "INCLUDE")

1. Comment - Dissolved Tracer Input Parameters

80
COM

80A1

COM = user specified comment for dissolved tracer input parameters

2. Dissolved Tracer Input Parameters

10	20	30	40	50	60	70	80
TROPT	TRICOPT	CONDRAT	CONINIT	THETAT	VSRATE	ASOL	ASAL

A10,5X,A5,6F10.3

TROPT = "CONSERV" - Conservative tracer (CONDRAT = 0.0)
"SIMPDECAY" - simple first order decay. Non-zero value of CONDRAT is required.
"PATHOGEN" - pathogen fate simulation. If TROPT = "PATHOGEN", user should specify proper values for CONDRAT, CONINT, THETAT, VSRATE, ASOL, and ASAL.

TRICOPT = Initial condition of dissolved tracer option: "DATA" or "FIXED"
If TRICOPT = "DATA", user must provide "init_tracer" file. Please refer to Table 10-28 for more details of format specification.
If TRICOPT = "FIXED", uniform value of CONINIT will be used.

CONDRAT = dissolved tracer decay rate (first-order decay) in day^{-1}

CONINIT = initial dissolved tracer concentration in mg/l, assumed spatially constant

THETAT = Temperature coefficient θ (default - 1.07)

VSRATE = Settling rates of bacteria (m/day)

ASOL = Coefficient of insolation (α) α=1. If α=0 then no dependency of decay on solar radiation

ASAL = Switch for decay rate dependency on salinity. ASAL = 1, salinity dependent and ASAL = 0, no salinity dependency.

NOTE: To simulate tracer as conservative substances users have to assign CONDRAT = 0, VSRATE = 0, ASOL = 0 and ASAL = 0.

3. Comment - Dissolved Tracer Concentrations at Open Boundaries

80
COM
80A1

COM = user specified comment for dissolved tracer concentrations at open boundaries

4. Number of Grid Elements

5
NUMEBCTR
I5

NUMEBCTR = total number of open boundary elements at which dissolved tracer concentrations will be specified

5. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

6. Location of Grid Elements and Dissolved Tracer Data

5	10	15	20	25	
ITRED	JTRED	ITREC	JTREC	CBDRYSL1(1)	... CBDRYSL1(IKSL)
4I5,100F5.0					

ITRED = i number of grid element where dissolved tracer is specified
JTRED = j number of grid element where dissolved tracer is specified
ITREC = i number of connecting grid element (nearest interior non-boundary grid element)
JTREC = j number of connecting grid element (nearest interior non-boundary grid element)
CBDRYSL1 = dissolved tracer concentration in mg/l at "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ITRED/JTRED/CBDRYSL1) is repeated for each location. Total number = NUMEBCTR (total number of boundary grid elements). The sequence (TIME/CBDRYSL1) is repeated for each observation.

Table 10-7: water_traceinp INPUT FILE

Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for dissolved tracer observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCTR = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then dissolved tracer concentrations **must** be specified at all open boundaries in the domain.

7. Comment - Dissolved Tracer Concentrations at River Discharges

80
COM

80A1

COM = user specified comment for dissolved tracer concentrations at river discharges

8. Number of Grid Elements

5
NUMQBCTR

I5

NUMQBCTR = total number of river discharges at which dissolved tracer concentrations will be specified

9. Location of Grid Elements

5	10	15	20
ITRQD	JTRQD	ITRQC	JTRQC

4I5

ITRQD = i number of grid element discharge enters
JTRQD = j number of grid element discharge enters
ITRQC = i number of connecting exterior boundary grid element
JTRQC = j number of connecting exterior boundary grid element

NOTE: Sequence ITRQD/JTRQD/ITRQC/JTRQC is repeated for each discharge location.

Table 10-7: water_traceinp INPUT FILE

10. Time of Observation

10
TIME

F10.1

TIME = time in hours
= 0.0 for initial time

11. Dissolved Tracer Data

10	20	30	80
CDIS1(1)	CDIS1(2)	CDIS1(3)	... CDIS1(NUMQBCTR)

8F10.1

CDIS1 = dissolved tracer concentration of river discharge in mg/l

NOTE: 1. The sequence (TIME/CDIS1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS1 values. However, a value of zero should be input for CDIS1 of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCTR = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then dissolved tracer concentrations **must** be specified at all river discharges in the domain.

NOTE: Only include the next data group (items 12 -14) if offshore discharges (diffuser outfalls) are specified in run_data (NUMDBC > 0 in Data Group G (Table 8-3B): Discharge Information)

12. Comment - Dissolved Tracer Concentrations at Offshore Discharges

80
COM

80A1

COM = user specified comment for dissolved tracer concentrations at offshore discharges

13. Number of Grid Elements

5
NUMDBCTR1
I5

NUMDBCTR1 = total number of offshore discharges at which dissolved tracer concentrations will be specified

14. Location of Grid Elements

5	10
ITRDD	JTRDD
2I5	

ITRDD = i number of grid element discharge enters
JTRDD = j number of grid element discharge enters

NOTE: Sequence ITRDD/JTRDD is repeated for each discharge location

15. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

16. Dissolved Tracer Data

10	20	30	80
CDIFF1(1)	CDIFF1(2)	CDIFF1(3)	... CDIFF1(NUMDBCTR1)
8F10.1			

CDIFF1 = dissolved tracer concentration of offshore discharge in mg/l

NOTE: The sequence (TIME/CDIFF1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-7: water_traceinp INPUT FILE

17. Comment-Dissolved Tracer Concentrations at Offshore Discharges in Loops

80
COM
80A1

COM = user specified comment for dissolved tracer concentrations at offshore discharges in loops

18. Number of Grid Elements

5
NUMDBCTR2
I5

NUMDBCTR2 = total number of offshore discharges in loops at which dissolved tracer concentrations will be specified

19. Time of Observations

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

20. Dissolved Tracer Data

10	20	30	80
DCDIFF1(1)	DCDIFF1(2)	DCDIFF1(3)	DCDIFF1(NUMDBCTR2)
8F10.1			

DCDIFF1 = dissolved tracer concentrations of offshore discharge in loops in mg/l

NOTE: The sequence (TIME/DCDIFF1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLDSTART runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOTSTART runs.

Table 10-7: water_traceinp INPUT FILE

21. Comment - Dissolved Tracer Point Source Loads

80
COM
80A1

COM = user specified comment for dissolved tracer point source loads

22. Number of Grid Elements and Point Source Loading Option

5	15
NUMPSTR	OPTPSTR
I5,6X,A4	

NUMPSTR = total number of grid elements at which dissolved tracer point source loads will be specified
OPTPSTR = "MASS" - dissolved tracer point sources are specified as a mass loading in kg/s
= "CONC" - dissolved tracer point sources are specified as instantaneous concentrations in mg/l

23. Location of Grid Elements

5	10	15
IPSTR	JPSTR	KPSTR
3I5		

IPSTR = i number of grid element where dissolved tracer point source is specified
JPSTR = j number of grid element where dissolved tracer point source is specified
KPSTR = k number of grid element where dissolved tracer point source is specified

NOTE: Sequence IPSTR/JPSTR/KPSTR is repeated for each point source location.

24. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

Table 10-7: water_traceinp INPUT FILE

25. Dissolved Tracer Data

10	20	80
PSLOAD(1)	PSLOAD(2)	.... PSLOAD(NUMPSTR)
8F10.1		

PSLOAD = dissolved tracer load in kg/s (OPTPSTR = "MASS")
= dissolved tracer load in mg/l (OPTPSTR = "CONC")

NOTE:

1. If OPTPSTR = "CONC", then the point source load is specified by instantaneously setting the dissolved tracer concentration in grid element (IPSTR, JPSTR,KPSTR) equal to PSLOAD (mg/l) at the specified time whenever PSLOAD > 0. No point source load will be specified at all times that PSLOAD = 0 mg/l.

2. The sequence (TIME/PSLOAD) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run) for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

Table 10-7: water_traceinp INPUT FILE

Table 10-8. coh_sed.inp INPUT FILE for SEDZL

NOTE: This file must be included for cohesive sediment transport simulations. (SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "MUD ")

1. Comment - Sediment Transport Control Parameters

80
COM
80A1

COM = user specified comment for sediment transport control parameters

2. Sediment Transport Control Parameters

10	20
NSEDBEG	NSBED
2I10	

NSEDBEG = time step at which to start sediment transport calculation
NSBED = frequency, in time steps, at which to calculate deposition/ resuspension fluxes

NOTE: If SEDTYPE = "BOTH", then NSEDBEG and NSBED must have the same values in both coh_sed.inp and noncoh_sed.inp.

3. Comment - Cohesive Sediment Deposition Parameters

80
COM
80A1

COM = user specified comment for cohesive sediment deposition parameters

4. Cohesive Sediment Deposition Parameters

10	20	30	40
ADEP	DEPEXP	TCRDEP	PDEPFORM
3F10.0, 5X,A5			

ADEP = A_{set} coefficient for floc settling speeds in μm/s
DEPEXP = b exponent for floc settling speeds
TCRDEP = critical shear stress for deposition of cohesive sediment in dynes/cm^2
PDEPFORM = "KRONE" - Krone formulation for probability of deposition (TCRDEP = τ_d in Eq. 5-11)

"PARTH" - Partheniades formulation for probability of deposition (TCRDEP = $\tau_{b,min}$ in Eq. 5-13)

5. Comment - Cohesive Sediment Resuspension Parameters

80
COM

80A1

COM = user specified comment for cohesive sediment resuspension parameters

6. Cohesive Sediment Resuspension Parameters

10	20	30	40
A0IN	RESEXP	EXPM	VARIA0N

3F10.0, 3X,A7

A0IN = a_o parameter in Eq. (5-5) in mg/cm^2, spatially-constant value when VARIA0N = "NEGLECT"
RESEXP = exponent n in Eq. (5-5), spatially-constant value when VARIA0N = "NEGLECT"
EXPM = exponent m in Eq. (5-5)
VARIA0N = "INCLUDE" - spatially-variable values of a_o and n in Eq. (5-5), input from a0_init and exp_init files
"NEGLECT" - spatially-constant values of a_o and n in Eq. (5-5), input as A0IN and RESEXP

7. Comment - Cohesive Sediment Bed Property Parameters

80
COM

80A1

COM = user specified comment for cohesive sediment bed property parameters

8. Cohesive Sediment Bed Property Parameters

10	20	30	40	50	60
DENCOH	VARIBULK	P0(1)	VARIPO	BFCOH	Z0COH

F10.0, 3X,A7, F10.0,3X,A7,2F10.0

DENCOH = bulk density of cohesive sediment bed in g/cm^3
VARIBULK = "INCLUDE" - spatially-variable sediment bed bulk density (g/cm^3), input

Table 10-8: coh_sed.inp INPUT FILE

from bed_bulkden file
"NEGLECT" - spatially-constant bulk density, input as DENCOH (cohesive bed) and DENNON (non-cohesive bed)

NOTE: If SEDTYPE = "BOTH", then VARIBULK must have same values in both co_sed.inp and non coh_sed.inp.

P0(1) = initial, spatially-constant fraction of fine class sediment in bed
VARIPO = "INCLUDE" - initial, spatially-variable fraction of fine class sediment in bed, input from p0_init file
"NEGLECT" - initial, spatially-constant fraction of fine class sediment in bed , input as P0(1)
BFCOH = bottom friction coefficient for cohesive sediments (non-dimensional)
Z0COH = bottom roughness coefficient for cohesive sediments, in meters

9. Comment - Cohesive Bed Consolidation Parameters

80
COM
80A1

COM = user specified comment for cohesive bed consolidation parameters

10. Cohesive Bed Consolidation Parameters

10	20	30	40	50	60	70
FTIME(1)	FTIME(2)	FTIME(3)	FTIME(4)	FTIME(5)	FTIME(6)	FTIME(7)
8F10.0						

FTIME(1) = time after deposition of sediment layer 1, in days
FTIME(2) = time after deposition of sediment layer 2, in days
FTIME(3) = time after deposition of sediment layer 3, in days
FTIME(4) = time after deposition of sediment layer 4, in days
FTIME(5) = time after deposition of sediment layer 5, in days
FTIME(6) = time after deposition of sediment layer 6, in days
FTIME(7) = time after deposition of sediment layer 7, in days

11. Comment - Initial Cohesive Bed Thickness

80
COM
80A1

COM = user specified comment for cohesive bed thickness

12. Initial Cohesive Bed Thickness

10	20	30	40	50	60	70
TSED0(1)	TSED0(2)	TSED0(3)	TSED0(4)	TSED0(5)	TSED0(6)	TSED0(7)

8F10.0

TSED0(1) = initial thickness of sediment layer 1, in cm
TSED0(2) = initial thickness of sediment layer 2, in cm
TSED0(3) = initial thickness of sediment layer 3, in cm
TSED0(4) = initial thickness of sediment layer 4, in cm
TSED0(5) = initial thickness of sediment layer 5, in cm
TSED0(6) = initial thickness of sediment layer 6, in cm
TSED0(7) = initial thickness of sediment layer 7, in cm

13. Comment - Cohesive Bed Critical Shear Stress

80
COM

80A1

COM = user specified comment for critical shear stress

14. Cohesive Bed Critical Shear Stress

10	20	30	40	50	60	70
TAUCR(1)	TAUCR(2)	TAUCR(3)	TAUCR(4)	TAUCR(5)	TAUCR(6)	TAUCR(7)

8F10.0

TAUCR(1) = critical shear stress of sediment layer 1, in dynes/cm^2
TAUCR(2) = critical shear stress of sediment layer 2, in dynes/cm^2
TAUCR(3) = critical shear stress of sediment layer 3, in dynes/cm^2
TAUCR(4) = critical shear stress of sediment layer 4, in dynes/cm^2
TAUCR(5) = critical shear stress of sediment layer 5, in dynes/cm^2
TAUCR(6) = critical shear stress of sediment layer 6, in dynes/cm^2
TAUCR(7) = critical shear stress of sediment layer 7, in dynes/cm^2

15. Comment - Initial Suspended Sediment Concentration

80
COM

80A1

COM = user specified comment for initial suspended sediment concentration

16. Initial Suspended Sediment Concentration

10
CSI
F10.0

CSI = initial, spatially-constant cohesive sediment concentration, in mg/l

17. Comment - Cohesive Sediment Concentrations at Open Boundaries

10
COM
80A1

COM = user specified comment for cohesive sediment concentrations at open boundaries

18. Number of Grid Elements

5
NUMEBSCE
I5

NUMEBCSE = total number of open boundary elements at which cohesive sediment concentrations will be specified

19. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

20. Location of Grid Elements and Cohesive Sediment Data

5	10	15	20	25	
ISEED	JSEED	ISEEC	JSEEC	CBDRYSL(1)	... CBDRYSL(IKSL)
4I5,100F5.0					

ISEED = i number of grid element where cohesive sediment is specified

Table 10-8: coh_sed.inp INPUT FILE

JSEED = j number of grid element where cohesive sediment is specified
ISEEC = i number of connecting grid element (nearest interior non-boundary grid element)
JSEEC = j number of connecting grid element (nearest interior non-boundary grid element)
CBDRYSL = cohesive sediment concentration in mg/l at "TIME" for each standard level (not sigma level)

NOTE:

1. Sequence (ISEED/JSEED/ISEEC/JSEEC/ CBDRYSL) is repeated for each location. Total number = NUMEBCSE (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for cohesive sediment observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCSE = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment concentrations **must** be specified at all open boundaries in the domain.

21. Comment - Cohesive Sediment Concentrations at River Discharges

10
COM
80A1

COM = user specified comment for cohesive sediment concentrations at river discharges

22. Number of Grid Elements

5
NUMQBCSE
I5

NUMQBCSE = total number of river discharges at which cohesive sediment concentrations will be specified

23. Location of Grid Elements

5	10	15	20
ISEQD	JSEQD	ISEQC	JSEQC
4I5			

Table 10-8: coh_sed.inp INPUT FILE

ISEQD = i number of grid element discharge enters
JSEQD = j number of grid element discharge enters
ISEQC = i number of connecting exterior boundary grid element
JSEQC = j number of connecting exterior boundary grid element

NOTE: Sequence ISEQD/JSEQD/ISEQC/JSEQC is repeated for each discharge location.

24. Time of Observation

10
TIME

F10.1

TIME = time in hours
= 0.0 for initial time

25. Cohesive Sediment Data

10	20	30	80
CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCSE)

8F10.1

CDIS = cohesive sediment concentration of river discharge in mg/l

NOTE:

1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCSE = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

26. Comment - Cohesive Sediment Loading in Diffuser Discharges

80
COM
80A1

COM = user specified comment for cohesive sediment loading in diffuser discharges

27. Number of Grid Elements

5
NUMDBCSE
15

NUMDBCSE = total number of diffusers at which cohesive sediment loading will be specified. If NUMDBCSE = 0, then terminate input.

28. Location of Grid Elements/Vertical Distribution of Diffuser Loadings

5	10	15	20	. . .110
IDDSE(NUMDBCSE)	JDDSE(NUMDBCSE)	VDDISTSE(1)	VDDISTSE(2)	VDDISTSE(KBM1)
2I5,20F5.0				

IDDSE = i number of grid element diffuser enters/leaves
JDDSE = j number of grid element diffuser enters/leaves
VDDISTSE = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDSE, JDDSE)
KBM1 = KB-1

NOTE:
1. Sequence (IDDSE/JDDSE/VDDISTSE) is repeated for each diffuser
2. More than one diffuser can be specified at the same location (IDDSE, JDDSE)

29. Time of Observation

10
TIME
F10.5

Table 10-8: coh_sed.inp INPUT FILE

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

30. Diffuser Loading Data

10	20	. . .	80
CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCSE)
8F10.5			

CDIFF = diffuser loading in kg/day.

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS*DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPSxDTI)/3600 for HOT START runs.

Table 10-9. noncoh_sed.inp INPUT FILE

NOTE: This file must be included for non-cohesive sediment transport simulations. (SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "SAND")

1. Comment - Sediment Transport Control Parameters

10
COM

80A1

COM = user specified comment for sediment transport control parameters

2. Sediment Transport Control Parameters

10	20
NSEDBEG	NSBED

2I10

NSEDBEG = time step at which to start sediment transport calculation
NSBED = frequency, in time steps, at which to calculate deposition/ resuspension fluxes

NOTE: If SEDTYPE = "BOTH", then NSEDBEG and NSBED must have the same values in both coh_sed.inp and noncoh_sed.inp.

3. Comment - Non-Cohesive Sediment Transport Parameters

10
COM

80A1

COM = user specified comment for non-cohesive sediment transport parameters

4. Non-Cohesive Sediment Transport Parameters

10	20	30	40	50
WS2	DENNON	VARIBULK	SUSARM	BEDTHI

2F10.0,3X,A7,2F10.0

WS2 = settling speed of non-cohesive sediment, in μm/s
DENNON = bulk density of non-cohesive sediment bed, in g/cm^3
VARIBULK = "INCLUDE" - spatially-variable sediment bed bulk density (g/cm^3), input from bed_bulkden file

"NEGLECT" - spatially-constant bulk density, input as DENCOH (cohesive bed) and DENNON (non-cohesive bed)

SUSARM = non-cohesive bed armoring constant (0 - 1.0 range)

NOTE: If SEDTYPE = "BOTH", then VARIBULK must have same values for both coh_sed.inp and noncoh_sed.inp

BEDTHI = initial thickness of non-cohesive bed, in cm

5. Comment - Initial Suspended Sediment Concentration

10
COM
80A1

COM = user specified comment for initial suspended sediment concentration

6. Initial Suspended Sediment Concentration

10
CSI
F10.0

CSI = initial, spatially-constant non-cohesive sediment concentration, in mg/l

7. Comment - Non-Cohesive Sediment Concentrations at Open Boundaries

10
COM
80A1

COM = user specified comment for non-cohesive sediment concentrations at open boundaries

8. Number of Grid Elements

5
NUMEBCSE
I5

NUMEBCSE = total number of open boundary elements at which non-cohesive sediment concentrations will be specified

9. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

10. Location of Grid Elements and Non-Cohesive Sediment Data

5	10	15	20	25	
ISEED	JSEED	ISEEC	JSEEC	CBDRYSL(1)	... CBDRYSL(IKSL)
4I5,100F5.0					

ISEED = i number of grid element where non-cohesive sediment is specified
JSEED = j number of grid element where non-cohesive sediment is specified
ISEEC = i number of connecting grid element (nearest interior non-boundary grid element)
JSEEC = j number of connecting grid element (nearest interior non-boundary grid element)
CBDRYSL = non-cohesive sediment concentration in mg/l at "TIME" for each standard level (not sigma level)

NOTE:

1. Sequence (ISEED/JSEED/ISEEC/JSEEC/ CBDRYSL) is repeated for each location. Total number = NUMEBCSE (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for non-cohesive sediment observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCSE = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment concentrations **must** be specified at all open boundaries in the domain.

11. Comment - Non-Cohesive Sediment Concentrations at River Discharges

10
COM
80A1

Table 10-9: noncoh_sed.inp INPUT FILE

COM = user specified comment for non-cohesive sediment concentrations at river discharges

12. Number of Grid Elements

5
NUMQBCSE
I5

NUMQBCSE = total number of river discharges at which non-cohesive sediment concentrations will be specified

13. Location of Grid Elements

5	10	15	20
ISEQD	JSEQD	ISEQC	JSEQC
4I5			

ISEQD = i number of grid element discharge enters
JSEQD = j number of grid element discharge enters
ISEQC = i number of connecting exterior boundary grid element
JSEQC = j number of connecting exterior boundary grid element

NOTE: Sequence ISEQD/JSEQD/ISEQC/JSEQC is repeated for each discharge location.

14. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

15. Non-cohesive Sediment Data

10	20	30	80
CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCSE)
8F10.1			

CDIS = non-cohesive sediment concentration of river discharge in mg/l

NOTE: 1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the

Table 10-9: noncoh_sed.inp INPUT FILE

run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCSE = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

16. Comment - Non-cohesive Sediment Loading in Diffuser Discharges

80
COM
80A1

COM = user specified comment for non-cohesive sediment loading in diffuser discharges

17. Number of Grid Elements

5
NUMDBCSE
I5

NUMDBCSE = total number of diffusers at which non-cohesive sediment loading will be specified. If NUMDBCSE = 0, then terminate input.

18. Location of Grid Element/Vertical Distribution of Diffuser Loadings

5	10	15	20	. . .	110
IDDSE(NUMDBCSE)	JDDSE(NUMDBCSE)	VDDISTSE(1)	VDDISTSE(2)		VDDISTSE(KBM1)
2I5,20F5.0					

IDDSE = i number of grid element diffuser enters/leaves
JDDSE = j number of grid element diffuser enters/leaves
VDDISTSE = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDSE, JDDSE)
KBM1 = KB-1

Table 10-9: noncoh_sed.inp INPUT FILE

NOTE: 1. Sequence (IDDSE/JDDSE/VDDISTSE) is repeated for each diffuser
2. More than one diffuser can be specified at the same location (IDDSE, JDDSE)

19. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

20. Diffuser Loading Data

10	20	. . .	80
CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCSE)
8F10.5			

CDIFF = diffuser loading in kg/day.

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS*DTI)/3600 (the duration of the run), for COLD START runs, and greater than 1END + (NSTEPSxDTI)/3600 for HOT START runs.

Table 10-9: noncoh_sed.inp INPUT FILE

Table 10-10. coh_trace.inp INPUT FILE

NOTE: This file must be included for cohesive sediment-bound transport simulations. (CHEMTRAN = " INCLUDE", SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "MUD ")

1. Comment - Sediment-Bound Transport Control Parameters

10
COM

80A1

COM = user specified comment for sediment-bound transport control parameters

2. Sediment-Bound Transport Control Parameters

10	20	30	40	50
CHEMI(1)	NCHEMLAY	CHEMTHIK	CHEMACT	CHEMDRAT

F10.0, I10, 4F10.0

CHEMI(1) = initial, spatially-constant, cohesive sediment-bound concentration (water column), in μg/l
NCHEMLAY = number of layers in sediment-bound tracer bed model
CHEMTHIK = thickness of layers in sediment-bound tracer bed model, in cm
CHEMACT = active layer thickness, in cm (CHEMACT ≥ CHEMTHIK)
CHEMDRAT = sediment-bound tracer decay rate (first-order decay), in day^{-1}

NOTE: NCHEMLAY, CHEMTHIK and CHEMACT must have the same values in both coh_trace.inp and noncoh_trace.inp

3. Comment - Cohesive Sediment-Bound Tracer Concentrations at Open Boundaries

10
COM

80A1

COM = user specified comment for cohesive sediment-bound tracer concentrations at open boundaries

4. Number of Grid Elements

5
NUMEBCCH
I5

NUMEBCCH = total number of open boundary elements at which cohesive sediment-bound tracer concentrations will be specified

5. Time of Observation

10
COM
80A1

TIME = time in hours
= 0.0 for initial time

6. Location of Grid Elements and Cohesive Sediment-Bound Tracer Data

5	10	15	20	25	
ICHED	JCHED	ICHEC	JCHEC	CBDRYSL(1)	... CBDRYSL(IKSL)
4I5,100F5.0					

ICHED = i number of grid element where cohesive sediment is specified
JCHED = j number of grid element where cohesive sediment is specified
ICHEC = i number of connecting grid element (nearest interior non-boundary grid element)
JCHEC = j number of connecting grid element (nearest interior non-boundary grid element)
CBDRYSL = cohesive sediment-bound tracer concentration in μg/l at "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ICHED/JCHED/ICHEC/JCHEC/ CBDRYSL) is repeated for each location. Total number = NUMEBCCH (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for cohesive tracer observations need not be the same as for elevation observations in run_data.

Table 10-10: coh_trace.inp INPUT FILE

2. If HYDTYPE = 'INTERNAL', then NUMEBCCH = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment-bound tracer concentrations **must** be specified at all open boundaries in the domain.

7. Comment - Cohesive Sediment-Bound Tracer Concentrations at River Discharges

10
COM
80A1

COM = user specified comment for cohesive sediment-bound tracer concentrations at river discharges

8. Number of Grid Elements

5
NUMQBCCH
I5

NUMQBCCH = total number of river discharges at which cohesive sediment-bound tracer concentrations will be specified

9. Location of Grid Elements

5	10	15	20
ICHQD	JCHQD	ICHQC	JCHQC
4I5			

ICHQD = i number of grid element discharge enters
JCHQD = j number of grid element discharge enters
ICHQC = i number of connecting exterior boundary grid element
JCHQC = j number of connecting exterior boundary grid element

NOTE: Sequence ICHQD/JCHQD/ICHQC/JCHQC is repeated for each discharge location.

10. Time of Observation

10
TIME
F10.1

Table 10-10: coh_trace.inp INPUT FILE

TIME = time in hours
= 0.0 for initial time

11. Cohesive Sediment-Bound Tracer Data

10	20	30	80
CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCCH)

8F10.1

CDIS = cohesive sediment-bound tracer concentration of river discharge in μg/l

NOTE: 1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCCH = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment-bound tracer concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

12. Comment - Cohesive Sediment-Bound Tracer Loading in Diffuser Discharges

80
COM

80A1

COM = user specified comment for cohesive sediment-bound tracer loading in diffuser discharges

13. Number of Grid Elements

5
NUMDBCCH

I5

Table 10-10: coh_trace.inp INPUT FILE

NUMDBCCH = total number of diffusers at which cohesive sediment-bound tracer loading will be specified. If NUMDBCCH = 0, then terminate input.

14. Location of Grid Elements/Vertical Distribution of Diffuser Loadings

5	10	15
IDDCH(NUMDBCCH)	JDDCH(NUMDBCCH)	VDDISTCH(1)

20	110
VDDISTCH(2)	...VDDISTCH(KBM1)

2I5,20F5.0

IDDCH = i number of grid element diffuser enters/leaves
JDDCH = j number of grid element diffuser enters/leaves
VDDISTCH = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDCH, JDDCH)
KBM1 = KB-1

NOTE:
1. Sequence (IDDCH/JDDCH/VDDISTCH) is repeated for each diffuser.
2. More than one diffuser can be specified at the same location (IDDCH, JDDCH).

15. Time of Observation

10
TIME

F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

16. Diffuser Loading Data

10	20	. . .	80
CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCCH)

8F10.5

Table 10-10: coh_trace.inp INPUT FILE

CDIFF = diffuser loading in kg/day

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS * DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-11. noncoh_trace.inp INPUT FILE

NOTE: This file must be included for non-cohesive sediment-bound transport simulations. (CHEMTRAN = " INCLUDE", SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "SAND")

1. Comment - Sediment-Bound Transport Control Parameters

10
COM

80A1

COM = user specified comment for sediment-bound transport control parameters

2. Sediment-Bound Transport Control Parameters

10	20	30	40	50
CHEMINIT	NCHEMLAY	CHEMTHIK	CHEMACT	CHEMDRAT

F10.0, I10, 4F10.0

CHEMINIT = initial, spatially-constant, non-cohesive sediment-bound concentration (water column), in μg/l
NCHEMLAY = number of layers in sediment-bound tracer bed model
CHEMTHIK = thickness of layers in sediment-bound tracer bed model, in cm
CHEMACT = active layer thickness, in cm (CHEMACT ≥ CHEMTHICK)
CHEMDRAT = non-cohesive sediment-bound tracer decay rate (first-order decay), in day^{-1}

NOTE: NCHEMLAY, CHEMTHIK and CHEMACT must have the same values in both coh_trace.inp and noncoh_trace.inp

3. Comment - Non-Cohesive Sediment-Bound Tracer Concentrations at Open Boundaries

10
COM

80A1

COM = user specified comment for non-cohesive sediment-bound tracer concentrations at open boundaries

4. Number of Grid Elements

5
NUMEBCCH
I5

NUMEBCCH = total number of open boundary elements at which non-cohesive sediment-bound tracer concentrations will be specified

5. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

6. Location of Grid Elements and Non-Cohesive Sediment-Bound Tracer Data

5	10	15	20	25	
ICHED	JCHED	ICHEC	JCHEC	CBDRYSL(1)	CBDRYSL(IKSL)

4I5,100F5.0

ICHED = i number of grid element where non-cohesive tracer is specified
JCHED = j number of grid element where non-cohesive tracer is specified
ICHEC = u number of connecting grid element (nearest interior non-boundary grid element)
JCHEC = j number of connecting grid element (nearest interior non-boundary grid element)
CBDRYSL = non-cohesive sediment-bound tracer concentration in μg/l at "TIME" for each standard level (not sigma level)

Table 10-11: noncoh_traceinp INPUT FILE

NOTE:

1. Sequence (ICHED/JCHED/ICHEC/JCHEC/ CBDRYSL) is repeated for each location. Total number = NUMEBCCH (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for non-cohesive tracer observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCCH = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment-bound tracer concentrations **must** be specified at all open boundaries in the domain.

7. Comment - Non-Cohesive Sediment-Bound Tracer Concentrations at River Discharges

10
COM
80A1

COM = user specified comment for non-cohesive sediment-bound tracer concentrations at river discharges

8. Number of Grid Elements

5
NUMQBCCH
I5

NUMQBCCH = total number of river discharges at which non-cohesive sediment-bound tracer concentrations will be specified

9. Location of Grid Elements

5	10	15	20
ICHQD	JCHQD	ICHQC	JCHQC
4I5			

ICHQD = i number of grid element discharge enters
JCHQD = j number of grid element discharge enters
ICHQC = i number of connecting exterior boundary grid element

Table 10-11: noncoh_traceinp INPUT FILE

JCHQC = j number of connecting exterior boundary grid element

NOTE: Sequence ICHQD/JCHQD/ICHQC/JCHQC is repeated for each discharge location.

10. Time of Observation

10
TIME

F10.1

TIME = time in hours
= 0.0 for initial time

11. Non-Cohesive Sediment-Bound Tracer Data

10	20	30	
CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCCH)

8F10.1

CDIS = non-cohesive sediment-bound tracer concentration of river discharge in μg/l

NOTE:

1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCCH = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment-bound tracer concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

12. Comment - Non-Cohesive Sediment-bound Tracer Loading in Diffuser Discharges

80
COM
80A1

COM = user specified comment for non-cohesive sediment-bound tracer loading in diffuser discharges

13. Number of Grid Elements

5
NUMDBCCH
I5

NUMDBCCH = total number of diffusers at which non-cohesive sediment-bound tracer loading will be specified. If NUMDBCCH = 0, then terminate input.

14. Location of Grid Elements/Vertical Distribution of Diffuser Loadings

5	10	15
IDDCH(NUMDBCH)	JDDCH(NUMDBCCH)	VDDISTCH(1)

20	...	110
VDDISTCH(2)	...	VDDISTCH(KBM1)

2I5,20F5.0

IDDCH = i number of grid element diffuser enters/leaves
JDDCH = j number of grid element diffuser enters/leaves
VDDISTCH = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDCH, JDDCH)
KBM1 = KB-1

NOTE:
1. Sequence (IDDCH/JDDCH/VDDISTCH) is repeated for each diffuser.
2. More than one diffuser can be specified at the same location (IDDCH, JDDCH).

15. Time of Observation

10
TIME
F10.5

Table 10-11: noncoh_traceinp INPUT FILE

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

16. Diffuser Loading Data

10	20	. . .	80
CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCCH)

8F10.5

CDIFF = diffuser loading in kg/day.

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS * DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-12. partrack.inp INPUT FILE

NOTE: This file must be included for particle tracking simulations. (PARTICLE = "INCLUDE")

1. Comment - Particle Tracking Input Parameters

10
COM

80A1

COM = user specified comment for particle tracking input parameters

2. Particle Tracking Input Parameters

8	16	24	32	40
NFREQ	NPART	IRELST	IRELEND	NSOURCE

6I8

NFREQ = number of time steps between each particle release
NPART = number of particles per release
IRELST = time step of first particle release
IRELEND = time step of last particle release
NSOURCE = number of particle sources

3. Particle Source Locations

8	16	24
ISOURCE(M)	JSOURCE(M)	KSOURCE(M)

3I8

ISOURCE(M) = i number of grid element for particle source M
JSOURCE(M) = j number of grid element for particle source M
KSOURCE(M) = k number of grid element for particle source M

NOTE:

1. There must be M = 1, ..., NSOURCE lines specified after line 2 for the particle source locations.

2. The corner_loc file is needed for particle tracking.

Table 10-12: partrack.inp INPUT FILE

Table 10-13. bed_mask INPUT FILE

NOTE: This file must be included for all sediment transport simulations.(SEDTRAN = "INCLUDE")

Input sediment bed map for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (IBMSK(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (40I3)
```

IBMSK = 0, cohesive sediment element
= 1, non-cohesive sediment element with suspended transport
= -1, hard bottom (no suspended transport)

Table 10-14. p0_init INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD", and VARIP0 = 'INCLUDE'

Input spatially-variable, sediment bed bulk density for the model grid as follows:

```
      DO 10 I = 1, IM
            READ (5,20) (PINIT(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.2)
```

PINIT = fraction of sediment bed initially composed of cohesive sediment

NOTE: only specify PINIT for cohesive elements, IBMSK = 0

Table 10-15. a0_init INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD" and VARIA0N = 'INCLUDE'

Input spatially-variable a_o values for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (A0(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (8E10.3)
```

A0 = a_0 value, for erosion potential in mg/cm^2

NOTE: only specify A0 for cohesive elements, IBMSK = 0

Table 10-16. exp_init INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD", and VARIA0N = 'INCLUDE'

Input spatially-variable exponent n values for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (REXP(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (8E10.3)
```

REXP = exponent n, for erosion potential in mg/cm^2

NOTE: only specify REXP for cohesive elements, IBMSK = 0

Table 10-17. bed_d50 INPUT FILE

NOTE: Include this file only if non-cohesive suspended transport is simulated (SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "SAND" and IBMSK = 1 for some elements in bed_mask)

Input spatially-variable D_{50} values for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (D50VAR(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.0)
```

D50VAR = median grain size of non-cohesive sediment (D_{50}), in microns

NOTE: only specify D_{50} for non-cohesive elements, IBMSK = 1

Table 10-18. bed_frac.mud INPUT FILE

NOTE: Include this file only if non-cohesive suspended transport is simulated (SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "SAND" and IBMSK = 1 for some elements in bed_mask)

Input spatially-variable, initial non-cohesive bed fractions for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (FPBED(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.3)
```

FPBED = fraction of sediment bed initially composed of suspended non-cohesive sediment, this is the clay/silt fraction in the bed.

NOTE: only specify FPBED for non-cohesive elements, IBMSK = 1

Table 10-19. bed_frac.sand INPUT FILE

NOTE: Include this file only if non-cohesive suspended transport is simulated (SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "SAND" and IBMSK = 1 for some elements in bed_mask)

Input spatially-variable, initial non-cohesive bed fractions for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (FPBED(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.3)
```

FPBED = fraction of sediment bed initially composed of suspended non-cohesive sediment, this is the fine sand fraction in the bed.

NOTE: only specify FPBED for non-cohesive elements, IBMSK = 1

Table 10-20. bed_bulkden INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD", and VARIBULK = 'INCLUDE'

Input spatially-variable, sediment bed bulk density for the model grid as follows:

```
      DO 10 I = 1, IM
        READ (5,20) (CBED(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.2)
```

CBED = sediment bed bulk density (g/cm^3)

Table 10-21. bed_chemic INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE" and CHEMTRAN = 'INCLUDE'

Input spatially-variable, initial bed concentration of sediment-bound tracer for the model grid as follows:

```
      DO 10 N = 1, NCHEMLAY
      DO 10 I = 1, IM
        READ (5,20) (CBEDCHEM (N,I,J),J=1,JM)
10    CONTINUE
20    FORMAT (10F8.0)
```

CBEDCHEM(N) = initial bed concentration of sediment-bound tracer in layer N (μg tracer/g sediment)

Table 10-22. hqi_geom INPUT FILE (UNFORMATTED)

```
READ(199) Z,ZZ,DZ,DZZ
READ(199) H1,H2,H,ANG
READ(199) ICNT
READ(199) (INDX(I), I = 1,ICNT)
READ(199) (JNDX(I), I =1,ICNT)
```

Unit 199	=	"hqi_geom"
Z	=	depth of the interface between sigma levels
ZZ	=	0.5 (Z(k) + Z(k+1))
DZ	=	thickness of the sigma level
DZZ	=	average depth of the grid element (m)
H1	=	distance in the ξ_1 direction at the center of the grid (m)
H2	=	distance in the ξ_2 direction at the center of the grid (m)
H	=	water depth (m)
ANG	=	angle between east and the ξ_1 direction measured in a counter-clockwise direction (deg)
ICNT	=	total number of water elements in horizontal plane
INDX(I)	=	i number of water element I
JNDX(I)	=	j number of water element I

Table 10-23. hqi_tran INPUT FILE (UNFORMATTED)

```
READ (IUTRN) TMIDDLE
READ (IUTRN) HPRNU
READ (IUTRN) ((WETGU(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGV(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGW(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGAAM(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGKH(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGKM(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGES(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGED(I,K),I=1,ICNT), K=1,KBM1)
```

IUTRN = 18 ("hqi_tran")

TMIDDLE	=	time at the middle of the averaging interval (days)
HPRNU	=	horizontal Prandtl number (momentum mixing/dispersive mixing)
WETGU	=	low-pass filtered volume flow rate in ξ_1 direction (m^3/s)
WETGV	=	low-pass filtered volume flow rate in ξ_2 direction (m^3/s)
WETGW	=	low-pass filtered vertical volume flow rate (m^3/s)
WETGAAM	=	low-pass filtered horizontal eddy viscosity (m^2/s)
WETGKH	=	low-pass filtered vertical eddy diffusivity (m^2/s)
WETGKM	=	low-pass filtered vertical eddy viscosity (m^2/s)
WETGES	=	initial surface elevation (m)
WETGED	=	time rate of change of elevation (m/s)

Table 10-24. wave_input INPUT FILE (UNFORMATTED)

READ (110) TIME
READ (110) WPERIOD
READ (110) WHEIGHT
READ (110) WDIR

Unit 110 = "wave_input"

TIME = time at which wave parameters were output (hours)
WPERIOD = mean wave period (seconds)
WHEIGHT = significant wave height (meters)
WDIR = wave direction, measured clockwise from North (degrees)

NOTE:

1. The wave parameters, usually generated by WAM, must be interpolated from the wave model grid to the ECOMSED model grid before storing in "wave_input."

2. The dimensions of the WPERIOD, WHEIGHT and WDIR arrays are (IM,JM), which is the same as used in ECOMSED.

Table 10-25. horcon2d.inp INPUT FILE

NOTE: This file must be included if the user specified HORCON (Data Group B.4) as "VARI" (X,A4).

1. Comment - 2-D HORCON Scale Factors

80
COM

80A1

COM = user specified comment for 2-D HORCON scale factors

2. Number of Grid Cells and Base HORCON Value

5	15
NVARHF	HORCON

(I5,F10.5)

NVARHF = number of grid cells to be scaled from the base HORCON value
HORCON = base HORCON value

3. Comment - Scaling Factors for HORCON

80
COM

80A1

4. 2-D HORCON Scale Factors

5	10	20
I	J	VARHF

(2I5,F10.5)

I, J = grid index
VARHF = HORCON scale factor

NOTE: Line 4 should be repeated by NVARHF

Table 10-26. Bfric2d.inp INPUT FILE

NOTE: This file must be included if the user specified BFRIC (Data Group B.2) as "VARI".

1. Comment - 2-D Bottom Friction Scale Factors

80
COM
80A1

COM = user specified comment for 2-D bottom friction scale factors

2. Number of Grid Cells and Base Bottom Friction Coefficient

5	15
NVARBF	BFRIC
(I5,F10.5)	

NVARBF = number of grid cells to be scaled from the base bottom friction coefficient BFRIC

BFRIC = minimum bottom friction coefficient (non-dimensional)

NOTE: ECOMSED will compute its base bottom drag coefficient based on equation (3-23a) and BFRIC. Then the scaling factors will be applied to the base drag coefficient.

3. Comment - Scaling Factors for bottom Drag Coefficients

80
COM
80A1

4. 2-D Bottom Drag Coefficient Scaling Factors

5	10	20
I	J	VARBF

(2I5,F10.5)

I, J = grid index
VARBF = bottom drag coefficient scaling factor

NOTE: Line 4 should be repeated by NVARBF

Table 10-27. umol2d.inp INPUT FILE

NOTE: This file must be included if the user specified UMOL (Data Group B.6) as "VARI" (6X,A4).

1. Comment - 2-D UMOL Scale Factors

80
COM
80A1

COM = user specified comment for 2-D UMOL scale factors

2. Number of Grid Cells and Base UMOL Value

5	15
NVARHF	UMOL
(I5,F10.5)	

NVARUF = number of grid cells to be scaled from the base UMOL value
UMOL = base UMOL value

3. Comment - Scaling Factors for UMOL

80
COM
80A1

4. 2-D UMOL Scale Factors

5	10	20
I	J	VARUF
(2I5,F10.5)		

I, J = grid index
VARUF = UMOL scale factor

NOTE: Line 4 should be repeated by NVARUF

Table 10-28. Z0b2d.inp INPUT FILE

NOTE: This file must be included if the user specified Z0B (Data Group B.1) as "VARI" (6X,A4).

1. Comment - 2-D Z0B Scale Factors

80
COM
80A1

COM = user specified comment for 2-D Z0B scale factors

2. Number of Grid Cells and Base Z0B Value

5	15
NVARZ0B	Z0B
(I5,F10.5)	

NVARZ0B = number of grid cells to be scaled from the base Z0B value

Z0B = base Z0B value

3. Comment - Scaling Factors for Z0B

80
COM
80A1

4. 2-D Z0B Scale Factors

5	10	20
I	J	VARZ0B
(2I5,F10.5)		

I, J = grid index

VARZ0B = Z0B scale factor

NOTE: Line 4 should be repeated by NVARZ0B

Table 10-29. init_tracer INPUT FILE

NOTE: This file must be included if the user specified TRICOPT (Table 10-7) as "DATA".

5	10	15	20	. . .	
I	J	CONC1(I,J,1)	CONC1(I,J,2)	. . .	CONC1(I,J,KSL)

2I5,100F5.0

I = i number of grid element in the ξ_1 direction
J = j number of grid element in the ξ_2 direction
CONC1 = dissolved tracer concentration at standard levels

NOTE: KSL = number of standard levels

Table 10-30. *bed.sdf* INPUT FILE

NOTE: This file must be included for sediment transport simulations (if SEDTRAN="INCLUDE" and SEDTYPE="SEDZLJ")

1. Comment - Sediment Transport Control Parameters

80
COM
80A1

COM = user specified comments for sediment transport control parameters

2. Sediment Transport Control Parameters

10	20	30	40
NSEDBEG	NSBEDNCHE	Z0BCOH	CFMIN

NSEDBEG = Timestep at which the sediment transport calculations begin.
NSBED = The number of hydrodynamic timesteps between each sediment transport timestep.
Z0BCOH = The Z_o of the sediment bed.
CFMIN = The minimum coefficient of friction for the shear stress calculation.

3. Comment - Sediment Bed Control Parameters

80
COM
80A1

COM = user specified comments for sediment bed control parameters

4. Sediment Bed Control Parameters

10	20	30	40
VAR_BED	NCALC_BL	CONTAU	DEP COEFF

VAR_BED = Switch for turning on variable sediment bed. If VAR_BED = 1, then 'core_field.sdf' is called so that spatial variation in bed properties can be defined.

NCLAC_BL = Switch for turning on bedload calculations. If NCLAC_BL = 1, then bedload transport is calculated, otherwise all material is assumed to transport as suspended load.

CONTAU = If CONTAU is greater than zero, then the number is specified as a constant shear stress throughout the domain. This is a useful tool for testing.

DEP COEFF = Fraction of the total sediment mass for a certain size class in a grid box that can settle in a single time step. Applies to both water-water and water-sediment settling.

5. Comment - Average Particle Size of Each Size Class

80
COM
80A1

COM = user specified comments for average particle size of each size class

6. Average Particle Size of Each Size Class

10	20	30	
D50(1)	D50(2)	D50(30	. . . D50(KSED)
8F10.3			

D50 = average particle size, D_{50}, of each size class (μm) where KSED is the number of size classes.

7. Comment - Critical Shear Stresses for Suspension

Table 10-30: bed.sdf INPUT FILE

80
COM
80A1

COM = user specified comments for critical shear stress for suspension

8. Critical Shear Stress for Suspension

10	20	30	
TCRDPS(1)	TCRDPS(2)	TCRDPS(3)	. . . TCRDPS(KSED)
8F10.3			

TCRCPS = critical shear stress for suspension of each size class in dynes/cm^2.

9. Comment - Critical Shear Stress for Erosion

80
COM
80A1

10. Critical Shear Stress for Erosion

10	20	30	
TAUCRS(1)	TAUCRS(2)	TAUCRS(3)	. . . TAUCRS(KSED)
8F10.3			

TAUCRS = critical shear stress for erosion of each size class in dynes/cm^2.

11. Comment – Average Particle Sizes of the Active Layer

80
COM
80A1

Table 10-30: bed.sdf INPUT FILE

COM = user specified comments for average particle sizes of the active layer

12. Average Particle Sizes of the Active Layer

10	20	30	
SCLOC(1)	SCLOC(2)	SCLOC(3)	. . . SCLOC(SCMAX)
8F10.3			

SCLOC = average particle sizes of the active layer. This is the start of input data for sediments in the active layer. After the formation of an active layer due to deposition and coarsening, the average particle size of the active layer or deposited layer is determined. Then for that particle size the appropriate erosion rate is used. SCLOC represents the average particle sizes of the active layer for which data are available. Above 200 μm, the Roberts et al. (1998) quartz data can be used. Below that, the data is gathered from field sediments brought back to the laboratory to determine their erosion rates.

13. Comment - Critical Shear Stress for Erosion of Active Layer Bed

80
COM
80A1

COM = user specified comments for critical shear stress for erosion of active layer

14. Critical Shear Stress for Erosion of Active Layer Bed

10	20	30	
TAUCRITE(1)	TAUCRITE(2)	TAUCRITE(3)	. . .TAUCRITE(SCMAX)
8F10.3			

TAUCRITE = critical shear stress for erosion of active layer bed at each SCLOC particle size. As the active layer particle size changes, SEDZLJ interpolates between these values to determine the critical shear stress of the active layer.

Table 10-30: bed.sdf INPUT FILE

15. Comment - Erosion Rates at Each Predetermined Shear Stress

80
COM
80A1

COM = user specified comment for erosion rates at each predetermined shear stress

16. Erosion Rates at Each Predetermined Shear Stress

```
DO SC=1,SCMAX
READ(407,'(8F10.3)') (ENRATE(SC,M),M=1,ITBM)
CONTINUE
```

ENRATE = Erosion rates (cm/s) at each predetermined shear stress (same shear stresses entered in 'erate.sdf' file) for each particular particle size SCLOC. SEDZLJ interpolates between these values as the active layer particle size changes.

ITBM = the number of shear stress intervals defined in '*comdeck*'

17. Comment – Initial Maximum Thickness of Each Deposited Layer

80
COM
80A1

COM = user specified comment for initial maximum thickness of each deposited layer

18. Initial Maximum Thickness of Each Deposited Layer

10
DTHICKM
F10.3

DTHICKM = initial maximum thickness in cm of each deposited layer. Once enough material has deposited into a layer to exceed this thickness, a new layer begins filling on top of the full layer. The mass of all layers is tracked directly, so the thickness of each layer will change as a function of time, but the mass will remain constant.

19. Comment – Bulk Density

80
COM
80A1

COM = user specified comment for bulk density

20. Bulk Density

10	20	30	40
DBINF	DBSUR	DBEXC	DSAND
4F10.3			

DBINF = maximum possible bulk density, ρ_∞, (g/cm^3).
DBSUR = surface bulk density of initially deposited cohesive material (g/cm^3).
DBEXC = 'c' coefficient in Eq. 6-44.
DBSAND = bulk density of pure sand at the surface as it deposits (g/cm^3).

21. Comments - Bed Consolidation and Swelling Rates

80
COM
80A1

COM = user specified comment for bed consolidation and swelling rates

22. Bed Consolidation and Swelling Rates

10	20
DCONR	DSWER
2F10.3	

DCONR = consolidation rate (1/day)
DSWER = swelling rate from Eq. 6-45 (1/day)

23. Comments - Coefficients for Erosion Rates and Critical Shear Stress

80
COM
80A1

COM = user specified comment for initial maximum thickness

Table 10-30: bed.sdf INPUT FILE

24. Coefficients for Erosion Rates and Critical Shear Stress

10	20	30	40
TAUSURF	EROA	ERON	EROM

4F10.3

TAUSURF	=	initial critical shear stress (dynes/cm^2) of a deposited cohesive layer at a bulk density of DBSUR.
EROA	=	'A' coefficient in Equation 6-46,
ERON	=	'n' and coefficient in Equation 6-47,
EROM	=	'm' coefficient in Equation 6-47,

EROA, ERON, and EROM are coefficients for the determination of erosion rates in Eq. 6-46 and critical shear stresses in Eq. 6-47.

25. Number and Averaging Interval of Computational History Output Sets

10	20	30	40	50	55
JTMS	AVGE	ITRNFORM	TRANZERO	IWET	OPTAVG

I10,F10.0,I10,F10.0,I10,1X,A4

JTMS	=	number of times all information necessary for STSWEM will be written in "gcm_sedtran"
AVGE	=	interval in time unit specified in OPTAVG for averaging the information to be written to "gcm_sedtran"
ITRNFORM	=	"0" - user specifies the "gcm_sedtran" output intervals
	=	"1" - output interval will be genrated by ECOmSED based on JTMS and NPLPFS
TRANZERO	=	the beginning time of "gcm_sedtran" output
IWET	=	"0" - "gcm_sedtran" output written for the entire grid
	=	"1" - "gcm_sedtran" output written for the wet grid only
OPTAVG	=	indicating the units of AVGE and TRANZERO. If the OPTAVG is not " ", "HOUR", "NDTI" or "MINU", user would be prompted to use one of the above units and resubmit the run

Table 10-30: bed.sdf INPUT FILE

Table 10-31.*erate.sdf* INPUT FILE

NOTE: 1. This file inputs all of the bed properties. Due to current model structure the first two layers are initially dummy layers and the actual sediment bed starts with layer 3. The input file still reads in data for the first two layers. It is recommended that the data for layers 1, 2, and 3 all be set equal to the initial surface interval data.

2. This file is required if SEDTRAN = 'INCLUDE', and SEDTYPE='SEDZLJ'

1. Comment - Critical Shear Stress for Erosion

80
COM
80A1

COM = user specified comments for sediment transport control parameters

2. Critical Shear Stress for Erosion

10 20 30
TAUTMP(1,1) TAUTMP(1,2) TAUTMP(1,3) . . . . . TAUTMP(1,LAYMAX)
(8F10.3)

TAUTMP = critical shear stress for erosion for each layer in core in dynes/cm^2. LAYMAX = maximum number of layers specified as a parameter in *comdeck*.

3. Comment -Wet Bulk Density for Each Layer

80
COM
80A1

COM = user specified comments for wet bulk density for each layer

4. Wet Bulk Density for Each Layer

10 20 30
BLKTMP(1) BLKTMP(2) BLKTMP(3) . . . . BLKTMP(LAYMAX)
8F10.3

BLKTMP = wet bulk density for each layer in the sediment bed in g/cm^3.

5. Comment - Mass Percentage of Each Size Class in Each Layer of Core

80
COM
80A1

COM = user specified comments for mass percentage of each size class in each layer of core

6. Mass Percentage of Each Size Class in Each Layer of Core

```
DO LL=1,LAYMAX
READ (408,'(8F10.3)') (PNEW(1,LL,K),K=1,KSED)
CONTINUE
```

PNEW = mass percentage of each size class in each layer of core. Read as a percentage not as a fraction (i.e. 100.0 = 100% of that size class).

KSED = number of particle size classes

7. Comment - Basic Shear Stresses and Erosion Rates of Core

80
COM
80A1

COM = user specified comments for basic shear stresses and erosion rates of core

9. Basic Shear Stresses and Erosion Rates of Core

```
DO M=1,ITBM
READ (408,*)  TAULOC(M)
READ(408,*) (E0RATE(1,LL,M),LL=1,LAYMAX)
CONTINUE
```

TAULOC = basic shear stresses for which data are available in dynes/cm^2. Note that this is the same for all cores as well as the intervals used in the erosion rate inputs in *bed.sdf*.

ITBM = number of shear stress intervals defined in '*comdeck*'.

E0RATE = measured erosion rates (cm/s) for each shear stress at each layer in the core. This value is the specified erosion rate at the top of each layer.

Table 10-31: erate.sdf INPUT FILE

10. Comments – Thickness of Each Layer

80
COM
80A1

COM = user specified comments for thickness of each layer

11. Thickness of Each Layer

READ(408,*) (TSED0S(LL),LL=1,LAYMAX)

TSED0S = thickness of each layer in cm.
For multiple cores, each core is repeated and defined as above and core locations are read in through '*core_field.sdf*'.

Table 10-32. *core_field.sdf* INPUT FILE

Note: This input file is needed if SEDTRAN='INLCUDE' and SEDTYPE='SEDZLJ'

```
READ(94,*)  INCORE
DO  J=JM-1,1,-1
READ(94,2000) (CORENO(I,J),I=2,IM-1)
CONTINUE
FORMAT (20I3)
```

INCORE = number of cores used
CORENO = appropriate core number for each location in the format shown.

Table 10-33.*coh_sed.inp* INPUT FILE for SEDZLJ

Note: This input file is needed if SEDTRAN='INLCUDE' and SEDTYPE='SEDZLJ'

1. Comment – Number of Sediment Size Classes, settling velocity option for cohesives, coefficient for settling velocity equation.

```
  80
COM
80A1
```

2. Number of Sediment Size Classes

```
    5          15                  30
KSED      WSOPT          WSET_COEFF
I5,A10,F15.6
```

KSED	=	number of sediment size classes
WSOPT	=	settling velocity option for cohesives. The current version only supports "KF_COAG" option.
WSET_COEFF	=	Coefficient to be used in settling velocity equation for cohesives

3. Comment - Open Boundary Conditions for Sediment Concentrations

```
  80
COM
80A1
```

4. Number of Open Boundary Grid Elements

```
          5
NUMEBCSE
I5
```

NUMEBCSE	=	total number of open boundary grid elements at which sediment concentrations will be specified

5. Time of Observation

```
   10
TIME
F10.3
```

TIME = time in hours, 0.0 for initial time

6. Location of Grid Elements and Sediment Concentration Data

```
DO N=1,NUMEBCSE
READ(IUT402,*) II,JJ,IIC,JJC
DO KK=1,KSED
READ(IUT402,*) (CBDRYSL(KK,N,K),K=1,KSL)
ENDDO
ENDDO
```

II,JJ = i and j element of grid element is specified
IIC,JJC = i and j element of connecting grid element (nearest interior non-boundary grid elements)
CBDRYSL = sediment concentration at open boundaries

NOTE: 1. Sequence (II,JJ,IIC, and JJC/CBDRYSL) is repeated for each location. Total number = NUMEBSCE (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPSxDTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEMPS x DTI)/3600 for HOT START runs. "TIME" for sediment observations need not be the same as for elevation observations in 'run_data'

2. If HYDTYPE = 'INTERNAL', then NUMEBSCE = NUMEBC (see Data Group F, Table 8-3: Open Boundary Condition Information in 'run_data'

7. Comment – Sediment Concentrations at River Discharges

80
COM
80A1

8. Sediment Concentrations at River Discharges

5
NUMQBCSE
I5

NUMQBSCE = total number of river discharges at which sediment concentrations will be specified

9. River Discharge Grid Elements

Table 10-33: coh_sed.inp INPUT FILE

```
DO N=1,NUMQBCSE
READ (IUT402,179)ISEQD(N),JSEQD(N),ISEQC(N),JSEQC(N)
CONTINUE
```

ISEQD	=	i number of grid element discharge enters
JSEQD	=	j number of grid element discharge enters
ISEQC	=	i number of connecting exterior boundary grid element
JSEQC	=	j number of connecting exterior boundary grid element

NOTE: Sequence ISEQD/JSEQD/ISEQD/JSEQD is repeated for each discharge location.

10. Time of Observation

10
TIME
F10.3

11. Sediment Data for River Discharge

```
DO KK=1,KSED
READ(IUT402,*)  (CDIS(KK,N),N=1,NUMQBCSE)
ENDDO
```

CDIS	=	sediment concentration of river discharge in mg/l
KSED	=	number of sediment size classes

NOTE: 1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPSxDTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEMPS x DTI)/3600 for HOT START runs. "TIME" for sediment observations need not be the same as for elevation observations in 'run_data'

2. If HYDTYPE = 'INTERNAL', then NUMQBCSE = NUMQBC (see Data Group G, Table 8-3B: Discharge Information in 'run_data'

Table 10-34. *timestep.inp* INPUT FILE

Note: This input file is needed if DTI = 'VARI' in 'run_data' file (i.e., user specifies a sequence of timesteps for a simulation. This feature is useful when simulating periods that include variable forcing, such as river flow or wind conditions, which result in temporal variations of minimum timesteps.

1. Comment

80
COM
80A1

2. Variable Timesteps

10	20	30
NUM	TNEXT	DTI

NUM = sequential number. This value is not used by ECOMSEDZLJ
TNEXT = Ending time (days) for use of specified timestep (DTI)
DTI = Timestep in seconds

NOTE:
1. There is no limit on the number of pairs of TNEXT and DTI.
2. TNEXT must increase monotonically and be an integer multiple of DTI
3. The last value of TNEXT must be greater than or equal to the ending time of the simulation.
4. Sequential values of DTI should change gradually to ensure stable model results. It is recommended that sequential values of DTI change by no more than 50 percent.

11.0 Model Output Data Structure

Table 11-1. Summary of Model Generated Output Files

File		
A. gcmprt	-	this file is a formatted output file. It contains all input information as well as many model computed values.
B. gcmplt	-	this file is an unformatted output file. It contains the computed results for all grid elements at the times and for the intervals specified in the file "run_data". The contents of this file are described in detail in this section.
C. gcmtsr	-	this file is an unformatted output file. It contains the computed values of elevation, current, temperature, salinity, conservative tracer and fluxes for grid elements specified in the "run_data" file, as well as run-time global integrals of various parameters. The contents of this file are described in detail in this section.
D. part_location	-	this file is a formatted output file. It contains the computed locations of particles during a particle tracking simulation. This file is generated if PARTICLE = "INCLUDE" in "run_data." The contents of this file are described in detail in this section.
E. gcm_tran	-	this file is an unformatted output file. It contains computed results of surface elevations, volume transports and dispersions as a time history. It is to be used as input to a water quality model. The contents of this file are described in detail in this section.
F. gcm_geom	-	this file is an unformatted output file. It contains grid segmentation information. It is to be used as input to a water quality model. The contents of this file are described in detail in this section.
G. startup	-	this file is an unformatted output file. It contains all the information for the hydrodynamic model run which will become the initial conditions for the "HOT START" runs. The user should move or copy the "startup" file to "restart" before making the next "HOT START" run.
H. cseds.out	-	this file is an unformatted output file. It contains hourly water column solids concentrations. The contents of this file are described in detail in this section.
I. cseds_pval.out	-	this file is an unformatted output file. It contains hourly size fractions of water column solids. The contents of this file are described in detail in this section.
J. dbl.out	-	this file is an unformatted output file. It contains hourly bed load depositional flux values. The contents of this file are described in detail in this section.
K.dbl2ac.out	-	this file is an unformatted output file. It contains hourly values of the cumulative bed load depositional flux values. The contents of this file are described in detail in this section.
L. ddd.out	-	this file is an unformatted output file. It contains hourly water column solids depositional flux values. The contents of this file are described in detail in this section.
M.ddd2ac.out	-	this file is an unformatted output file. It contains hourly values of the cumulative water column solids depositional flux values. The contents of this file are described in detail in this section.
N. ee.out	-	this file is an unformatted output file. It contains hourly sediment erosional flux values. The contents of this file are described in detail in this section.

O. ee2ac.out - this file is an unformatted output file. It contains hourly values of the cumulative sediment erosional flux values. The contents of this file are described in detail in this section.

P. gcmsedplt - this file is an unformatted output file. It contains sediment transport model output for HydroQual's proprietary model output viewer

Q. gcm_sedtran - this file is an unformatted output file. It contains sediment transport model output information for linkage to the organic carbon fate model (STSWEM). The contents of this file are described in detail in this section.

R. psus.out - this file is an unformatted output file. It contains hourly fractions of resuspension to the water column (fraction to bedload is 1 - PSUS). The contents of this file are described in detail in this section.

S. qsed.out - this file is an unformatted output file. It contains resuspension flux to the water column printed at hourly intervals. The contents of this file are described in detail in this section.

T. qbsed.out - this file is an unformatted output file. It contains resuspension flux to bed load printed at hourly intervals. The contents of this file are described in detail in this section.

U. sedtec2d.dat - this file is a formatted output file. It contains two dimensional sediment transport output, including bed elevation change, grain shear stress, bed load fluxes and vertically averaged water column solids concentration printed at hourly intervals.

V. sedtec3d.dat - this file is a formatted output file. It contains three dimensional sediment transport output, water column solids concentration and water velocity printed at hourly intervals.

Table 11-1: Summary of Model Generated Output Files

Table 11-2. gcmplt OUTPUT FILE (UNFORMATTED)

```
      READ(20) IM,JM,KB
      READ(20) EBCM,QBCM, NCHEMLAY
      READ(20) DTI,GRAV,UMOL,TOR, TRACER, SEDTRAN, CHEMTRAN
      READ(20) NUMEBC
      READ(20) (IETA(I),JETA(I),ICON(I),JCON(I),I=1,NUMEBC)
      READ(20) NUMQBC
      READ(20) (IQC(I),JQC(I),I=1,NUMQBC)
      READ(20) H
      READ(20) H1
      READ(20) H2
      READ(20) ANG
      READ(20) DUM
      READ(20) DVM
      READ(20) FSM
C
      DO 1000 JHIST=1,JHM
        READ(20) TMIDDLE
        READ(20) ARCET
        IF(TOR.EQ.'BAROTROPIC') THEN
          READ(20) ((ARCU (I,J,1),I=1,IM),J=1,JM)
          READ(20) ((ARCV (I,J,1),I=1,IM),J=1,JM)
          READ(20) ((ARCUX(I,J,1),I=1,IM),J=1,JM)
          READ(20) ((ARCVX(I,J,1),I=1,IM),J=1,JM)
        IF (TRACER.EQ.'INCLUDE') READ (20) ((ARCC(I,J,1),I=1,IM),J=1,JM)
        IF (SEDTRAN.EQ.'INCLUDE') THEN
          READ (20) ((ARCSED1(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCSED2(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCTHIK(I,J),I=1,IM),J=1,JM)
          ENDIF
        IF (CHEMTRAN.EQ.'INCLUDE') THEN
          READ (20) ((ARCCHEM1(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCCHEM2(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCPBED(N,I,J),I=1,IM),J=1,JM),N=1,NCHEMLAY)
          ENDIF
      ELSE
          READ(20) Z
          READ(20) ZZ
          READ(20) DZ
          READ(20) ARCU
          READ(20) ARCV
          READ(20) ARCUX
          READ(20) ARCVX
          READ(20) ARCT
          READ(20) ARCS
          READ(20) ARCW
          READ(20) ARCKH, ARCKM
        IF (TRACER.EQ.'INCLUDE') READ(20) ARCC
        IF (SEDTRAN.EQ.'INCLUDE') THEN
          READ (20) ARCSED1
          READ (20) ARCSED2
          READ (20) ARCTHIK
          READ (20) ARCTAU
          ENDIF
        IF (CHEMTRAN.EQ.'INCLUDE') THEN
```

```
                READ (20) ARCCHEM1
                READ (20) ARCCHEM2
                READ (20) ((ARCPBED(N,I,J),I=1,IM),J=1,JM),N=1,NCHEMLAY)
              ENDIF
1000 CONTINUE
```

Unit 20	=	"gcmplt"
IM	=	total number of grid elements in the ξ_1 direction
JM	=	total number of grid elements in the ξ_2 direction
KB	=	number of sigma levels
EBCM	=	maximum number of elevation boundary grid elements
QBCM	=	maximum number of discharge boundary grid elements
DTI	=	time step of the internal mode (sec)
GRAV	=	gravitational acceleration (m^2/sec)
UMOL	=	constant or background mixing (m^2/sec)
TOR	=	type of run ("BAROTROPIC"/"PROGNOSTIC"/"DIAGNOSTIC")
NCHEMLAY	=	number of layers in sediment-bound tracer bed model
TRACER	=	control parameter for dissolved tracer transport
SEDTRAN	=	control parameter for sediment transport
CHEMTRAN	=	control parameter for sediment-bound tracer transport
NUMEBC	=	total number of elevation boundary grid elements
IETA	=	i number of grid element where elevation is specified
JETA	=	j number of grid element where elevation is specified
ICON	=	i number of connecting grid element (nearest interior non-boundary grid element)
JCON	=	j number of connecting grid element (nearest interior non-boundary grid element)
NUMQBC	=	total number of discharge boundary grid elements
IQC	=	i number of grid element where discharge enters/leaves
JQC	=	j number of grid element where discharge enters/leaves
H	=	average depth of grid element (m)
H1	=	distance in the ξ_1 direction at the center of the grid (m)
H2	=	distance in the ξ_2 direction at the center of the grid (m)
ANG	=	angle between east and the ξ_1 direction measured in a counter-clockwise direction (deg)
DUM	=	land/water mask at the U interface of the grid element
DVM	=	land/water mask at the V interface of the grid element
FSM	=	land/water mask at the center of the grid element
TMIDDLE	=	time at the middle of the time interval (days)
ARCET	=	free surface elevation of the grid element (m)
Z	=	depth of the interface between sigma levels
	=	0.0 at the surface
	=	-1.0 at the bottom
ZZ	=	intermediate depth between sigma levels
DZ	=	thickness of the sigma level
	=	Z(K) - Z(K+1)
ARCU	=	velocity component in the ξ_1 direction (m/sec)
ARCV	=	velocity component in the ξ_2 direction (m/sec)
ARCUX	=	transport component in the ξ_1 direction (m^2/sec)
ARCVX	=	transport component in the ξ_2 direction (m^2/sec)
ARCT	=	temperature of the grid element (°C)
ARCS	=	salinity of the grid element (psu)
ARCW	=	vertical velocity (m/sec)
ARCKH	=	vertical eddy diffusivity (m^2/sec)
ARCKM	=	vertical eddy viscosity (m^2/sec)
ARCC	=	conservative tracer concentration (only included if TRACER = "INCLUDE")

Table 11-2: gcmplt OUTPUT FILE (UNFORMATTED)

ARCSED1	=	cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
ARCSED2	=	non-cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
ARCTHIK	=	sediment bed elevation change (cm) (only included if SEDTRAN = "INCLUDE")
ARCTAU	=	bottom shear stress for use in sediment transport (dynes/cm^2)
ARCCHEM1	=	cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
ARCCHEM2	=	non-cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
ARCPBED	=	sediment bed concentration of sediment-bound tracer (ppm) (only included if CHEMTRAN = "INCLUDE")

Table 11-3. gcmtsr OUTPUT FILE (UNFORMATTED)

```
              READ(30) TOR, TRACER, SEDTRAN, CHEMTRAN
              READ(30) KBM1, NCHEMLAY
              READ(30) EPTS
              READ(30) (INXIE(N),INXJE(N),N=1,EPTS)
              READ(30) VPTS
              READ(30) (INXIV(N),INXJV(N),N=1,VPTS)
              READ(30) (ANG (INXIV(N),INXJV(N)),N=1,VPTS)
              READ(30) FPTS
              READ(30) (ISFLX(N),JSFLX(N),DIRFLX(N),NFLXE(N),N=1,FPTS)
C
              DO 1000 I=1,ID
                READ(30) TMIDDLE
                READ(30) (ESAVE(N),N=1,EPTS)
              IF(TOR.EQ.'BAROTROPIC') THEN
                   READ(30) (UZSAVE(N,1),VZSAVE(N,1), N=1,VPTS)
                IF (TRACER.EQ.'INCLUDE') READ (30) (C1ZSAVE(N,1),N=1,VPTS)
                IF (SEDTRAN.EQ.'INCLUDE') THEN
                   READ (30)  (C1SAVE(N,1),C2SAVE(N,1),N=1,VPTS)
                   READ (30)  (THSAVE(N),N=1,VPTS)
                   READ(30) (TAUSAVE(N,1), N-1,VPTS)
                   ENDIF
                IF (CHEMTRAN.EQ.'INCLUDE') THEN
                   READ (30)  (P1SAVE(N,1),P2SAVE(N,1),N=1,VPTS)
                   READ (30)  ((PBEDSAVE(N,LL),N=1,VPTS),LL=1,NCHEMLAY)
                   ENDIF
                   READ(30) (CCFLUX(N,1),N=1,FPTS)
                   READ(30) ESUM,TKE,APE
                ELSE
                   READ(30) (DZSAVE(N),N=1,VPTS)
                   READ(30) ((UZSAVE(N,K),VZSAVE(N,K),SZSAVE(N,K),TZSAVE(N,K),
                              N=1,VPTS),K=1,KBM1), (((KHZSAVE(N,K), KMZSAVE(N,K), N = VPTS, K = 1, KBM1)
                IF (TRACER.EQ.'INCLUDE') READ (30) ((C1ZSAVE(N,K),N=1,VPTS),
                    K=1,KBM1)
                IF (SEDTRAN.EQ.'INCLUDE') THEN
                   READ (30)  ((C1SAVE(N,K),C2SAVE(N,K),N=1,VPTS),K=1,KBM1)
                   READ (30)  (THSAVE(N),N=1,VPTS)
                   READ (30)  (TAUSAVE(N,KB),–1,VPTS)
                   ENDIF
                IF (CHEMTRAN.EQ.'INCLUDE') THEN
                   READ (30)  ((P1SAVE(N,K),P2SAVE(N,K),N=1,VPTS),K=1,KBM1)
                   READ (30)  ((PBEDSAVE(N,LL),N=1,VPTS),LL=1,NCHEMLAY)
              ENDIF
                READ(30) ((CCFLUX(N,K),N=1,FPTS),K=1,KBM1)
                   READ(30) VSTOR,EM,APEC,TSUM,SSUM
1000 CONTINUE
```

Unit 30	=	"gcmtsr"
TOR	=	type of run ("BAROTROPIC"/"PROGNOSTIC"/"DIAGNOSTIC")
NCHEMLAY	=	number of layers in sediment-bound tracer bed model
TRACER	=	control parameter for dissolved tracer transport
SEDTRAN	=	control parameter for sediment transport
CHEMTRAN	=	control parameter for sediment-bound tracer transport
KBM1	=	number of sigma layers (KB-1)
EPTS	=	number of grid elements with elevation time series

INXIE	=	i number of user specified grid element
INXJE	=	j number of user specified grid element
VPTS	=	number of grid elements with current time series
INXIV	=	i number of user specified grid element
INXJV	=	j number of user specified grid element
ANG	=	angle in degrees between east and ξ_1 direction measured in a counter-clockwise direction
FPTS	=	number of user specified grid elements with cross sectional flux time series
ISFLX	=	i number of user specified grid element in which cross section begins
JSFLX	=	j number of user specified grid element in which cross section begins
DIRFLX	=	direction of the cross section
	=	"IDIR" - cross section in the ξ_1 direction
	=	"JDIR" - cross section in the ξ_2 direction
NFLXE	=	number of grid elements in the cross section
TMIDDLE	=	time at the middle of the time interval (days)
ESAVE	=	surface elevation of the user specified grid element (m)
DZSAVE	=	total depth of the user specified grid element (m)
	=	bottom topography + elevation
UZSAVE	=	U velocity averaged at the center of the user specified grid element (m/sec)
VZSAVE	=	V velocity averaged at the center of the user specified grid element (m/sec)
SZSAVE	=	salinity of the user specified grid element (psu)
TZSAVE	=	temperature of the user specified grid element (°C)
KHZSAVE	=	vertical eddy diffusivity (m^2/sec)
KMZSAVE	=	vertical eddy viscosity (m^2/sec)
CCFLUX	=	mass transport averaged at the center of the user specified grid element (m^3/sec)
ESUM	=	average surface elevation in the modeling domain (m)
TKE	=	volume averaged total kinetic energy (joule)
APE	=	volume averaged available potential energy (joule)
VSTOR	=	volume storage (m^3)
EM	=	excess mass (kg)
APEC	=	excess volume averaged available potential energy (joule)
SSUM	=	volume averaged salinity in the modeling domain (psu)
TSUM	=	volume averaged temperature in the modeling domain (°C)
C1ZSAVE	=	conservative tracer concentration (only included if TRACER = "INCLUDE")
C1SAVE	=	cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
C2SAVE	=	non-cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
THSAVE	=	sediment bed elevation change (cm) (only included if SEDTRAN = "INCLUDE")
TAUSAVE	=	bottom shear stress for use in sediment transport (dynes/cm^2)
P1SAVE	=	cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
P2SAVE	=	non-cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
PBEDSAVE	=	sediment bed concentration of sediment-bound tracer (ppm) (only included if CHEMTRAN = "INCLUDE")

Table 11-3: gcmtsr OUTPUT FILE (UNFORMATTED)

Table 11-4. part_location OUTPUT FILE (FORMATTED)

```
DO JHIST = 1, JHM
    DO LL = 1, NSOURCE
        DO NN = 1, NGRADELOOP

            READ(40,´(3I8,F10.4)´)LL,NN,NPART,TIME
            READ(40,´(20F10.1)´)(XOUTP(NP),NP=1,NPART)
            READ(40,´(20F10.1)´)(YOUTP(NP),NP=1,NPART)
            READ(40,´(20F10.1)´)(ZOUTP(NP),NP=1,NPART)
        ENDDO
    ENDDO
ENDDO
```

Unit 40	=	“part_location
NSOURCE	=	number of particle sources
NGRADELOOP	=	number of releases
NPART	=	number of particles per release
TIME	=	time (days) when the locations of released particles are recorded
XOUTP	=	particle location in x-direction (East) (m)
YOUTP	=	particle location in y-direction (North) (m)
ZOUTP	=	particle location in z-direction (Up) (m)

Table 11-5. gcm_tran OUTPUT FILE (UNFORMATTED)

```
      DO 1000 JTRAC=1,JTM
           READ(10) TMIDDLE
           READ(10) (((ULPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
           READ(10) (((VLPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
           READ(10) WLPF
           READ(10) (((AAMAX(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
           READ(10) (((AAMAY(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
           READ(10) KHLPF
           READ(10) KMLPF
           READ(10) ES
           READ(10) ED
           READ(10) (((SLPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
           READ(10) (((TLPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
1000 CONTINUE
```

Unit 10	=	"gcm_tran"
TMIDDLE	=	time at the middle of the time averaging interval (days)
ULPF	=	low pass filtered volume flow rate in the ξ_1 direction (m3/sec)
VLPF	=	low pass filtered volume flow rate in the ξ_2 direction (m^3/sec)
WLPF	=	low pass filtered vertical volume flow rate (m^3/sec)
AAMAX	=	low pass filtered horizontal eddy viscosity in ξ_1 direction (m^2/sec)
AAMAY	=	low pass filtered horizontal eddy viscosity in ξ_2 direction (m^2/sec)
KHLPF	=	low pass filtered vertical eddy diffusivity (m^2/sec)
KMLPF	=	low pass filtered vertical eddy viscosity (m^2/sec)
ES	=	initial surface elevation (m)
ED	=	time rate of change of elevation (m/sec)
SLPF	=	low pass filtered salinity (psu)
TLPF	=	low pass filtered temperature (°C)

Table 11-6. gcm_geom OUTPUT FILE (UNFORMATTED)

```
READ(10) DZ,DZZ
READ(10) H,H1,H2,TPS
READ(10) ANG, NU
```

Unit 10 = "gcm_geom"

DZ	=	thickness of the sigma level
DZZ	=	average depth of the grid element (m)
H1	=	distance in the ξ_1 direction at the center of the grid (m)
H2	=	distance in the ξ_2 direction at the center of the grid (m)
TPS	=	land/water mask at the center of the grid element
ANG	=	angle between east and the ξ_1 direction measured in a counter- clockwise direction (deg)
NU	=	coefficient in time filter (non-dimensional)

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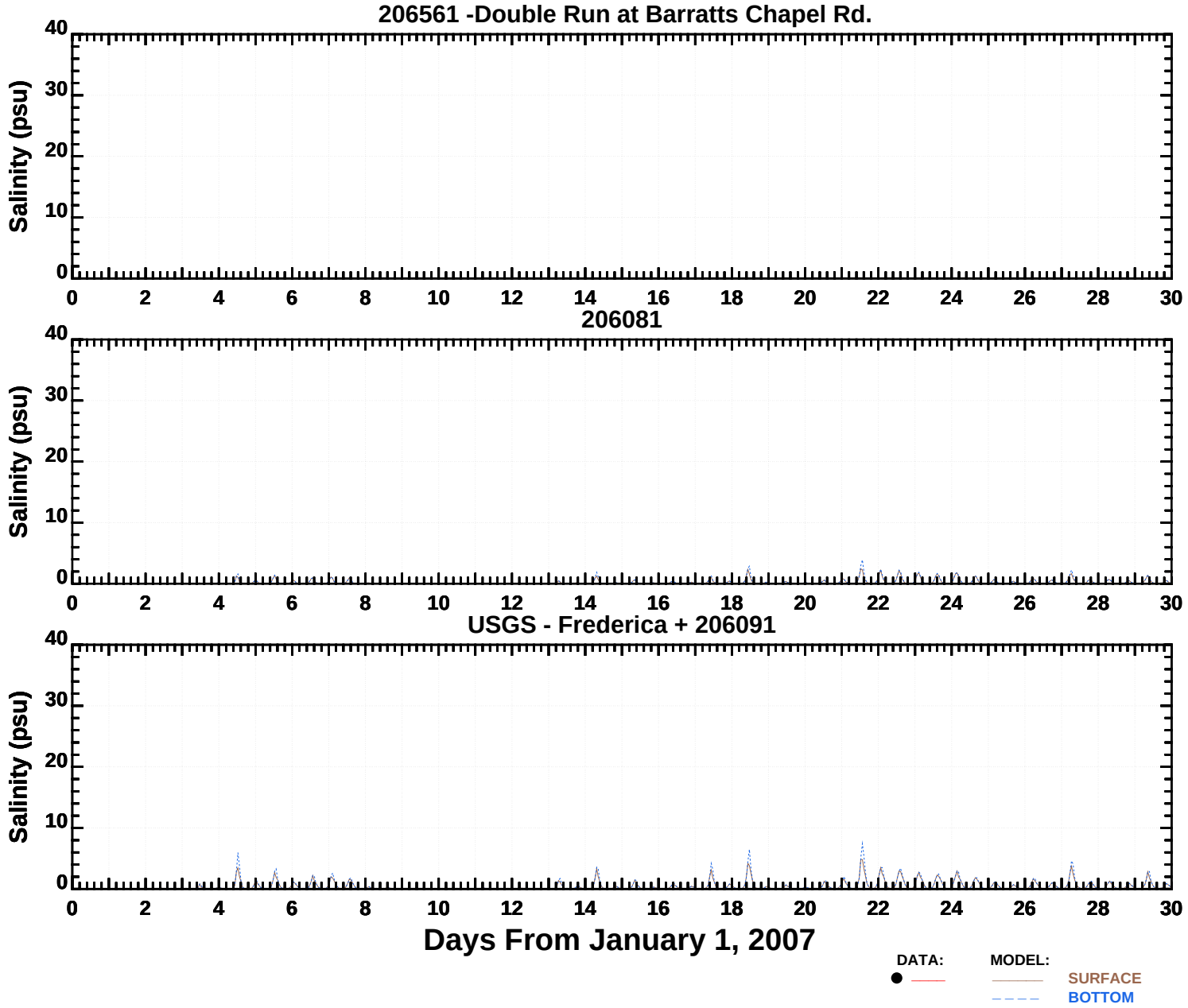
APPENDIX 4

HYDRODYNAMIC MODEL
SALINTY & TEMPERATURE
CALIBRATION/VALIDATION
FIGURES



DNREC Study
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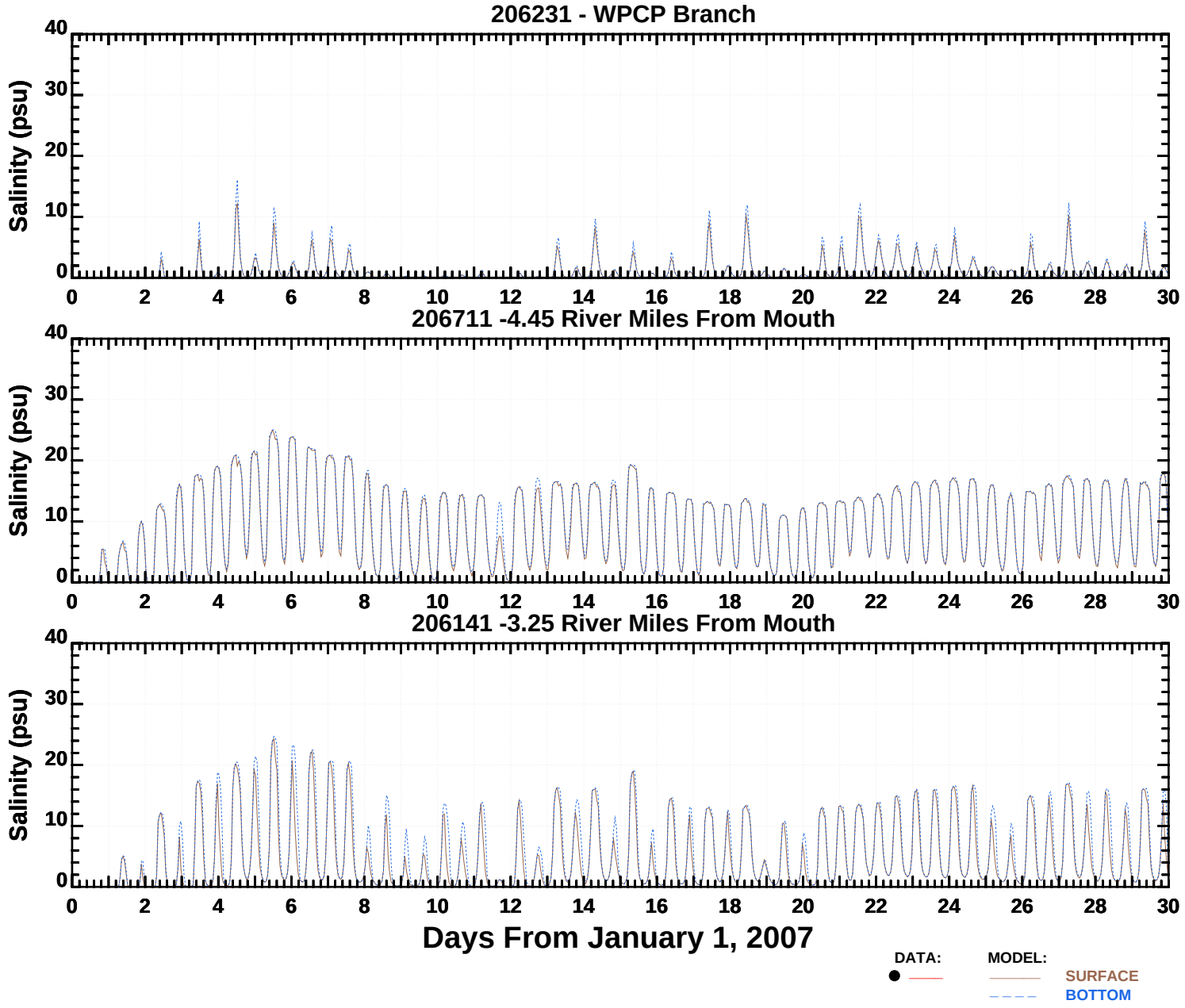
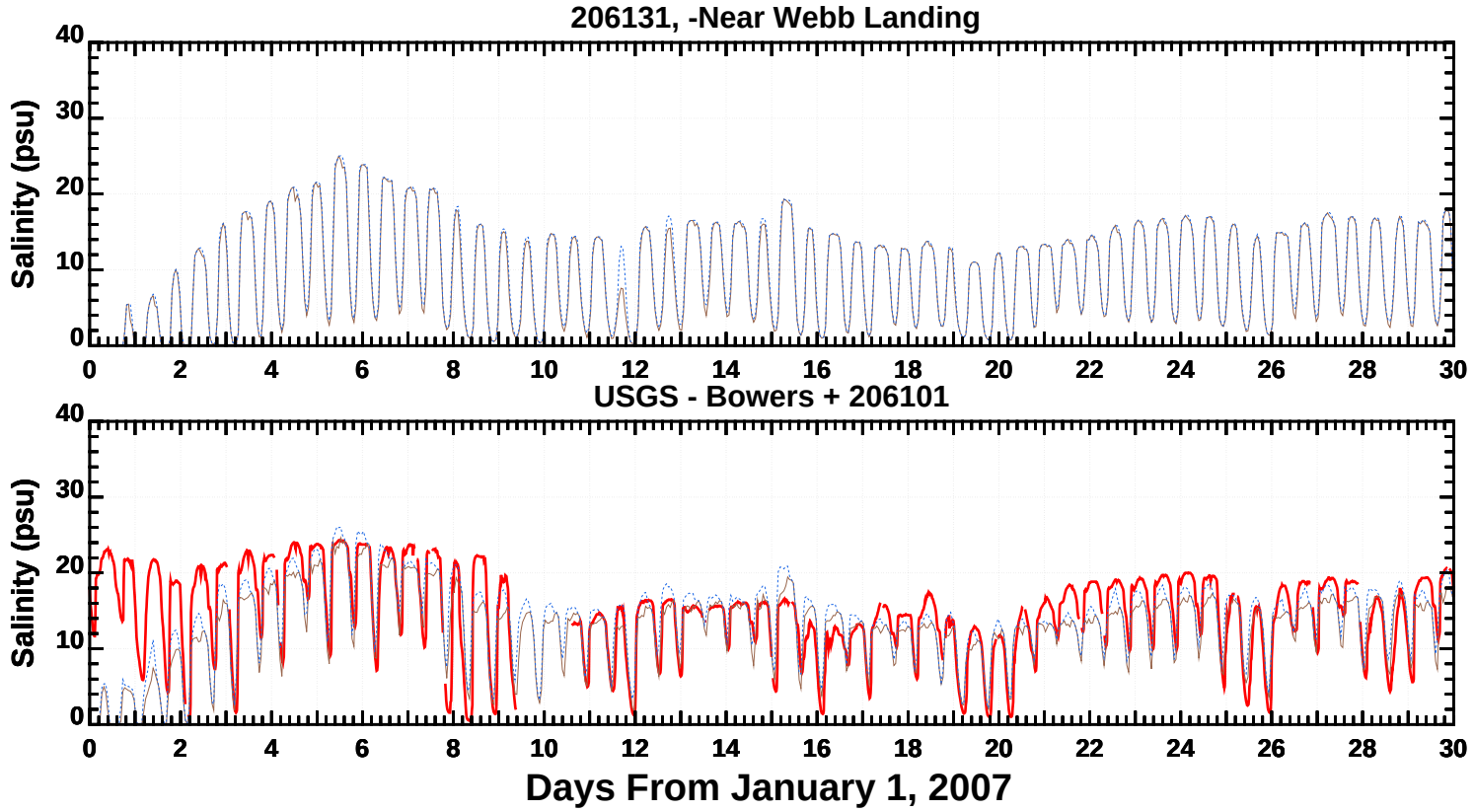
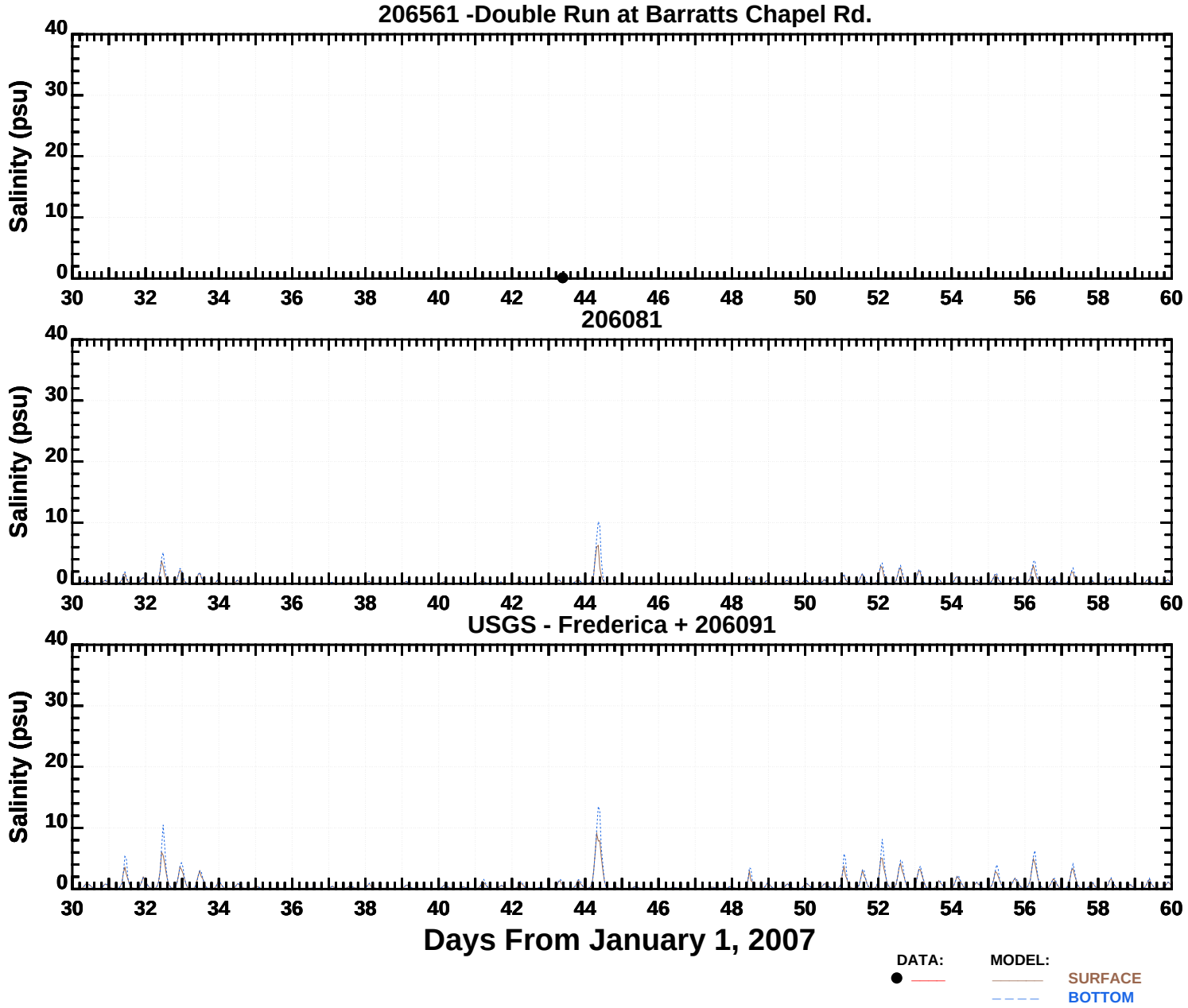
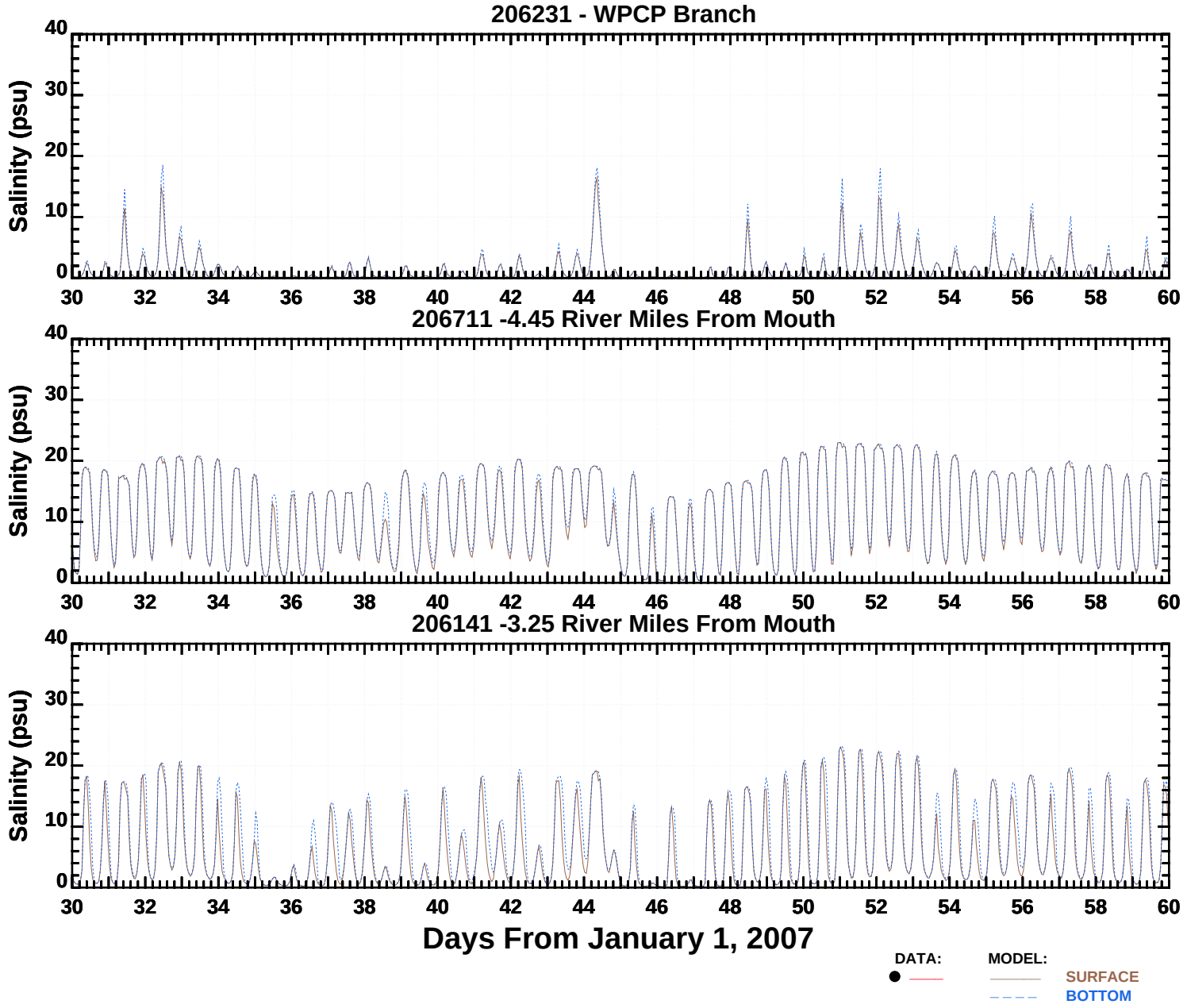
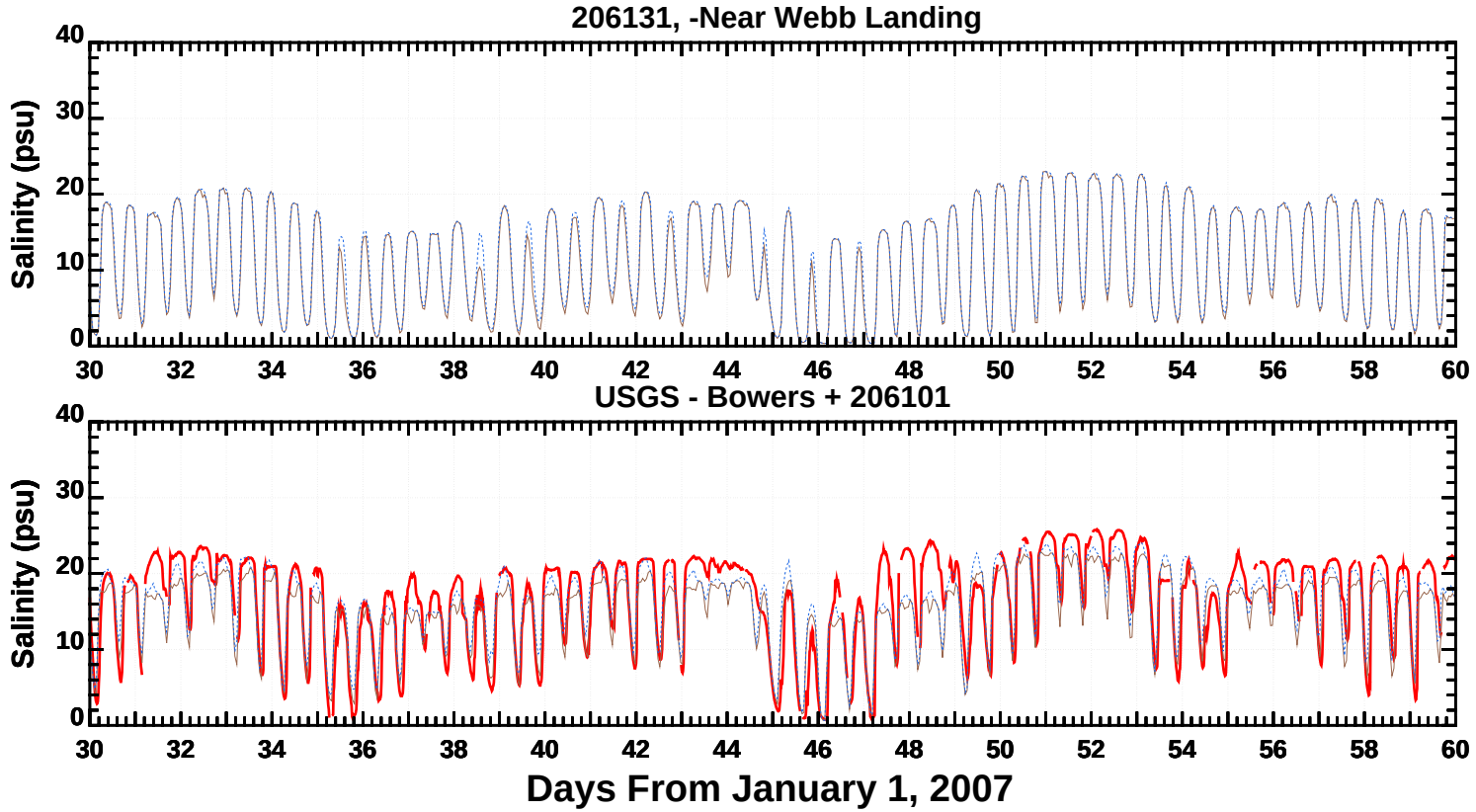

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: MODEL:
SURFACE
BOTTOM


206561 -Double Run at Barratts Chapel Rd.
Salinity (psu)
0
10
20
30
40
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
206081
USGS - Frederica + 206091
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM

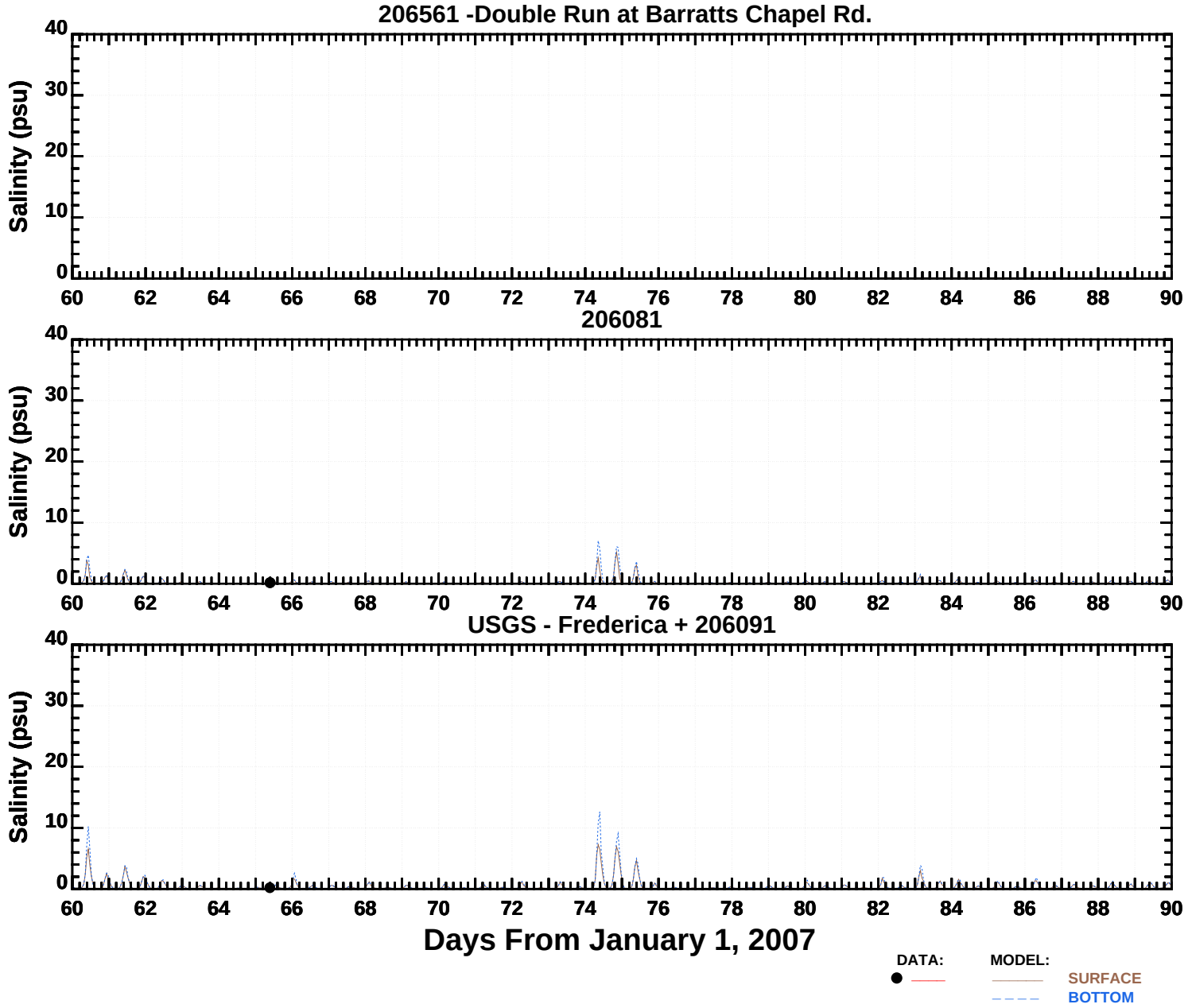

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: MODEL:

SURFACE

BOTTOM



DNREC Study
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Page 1 of 3
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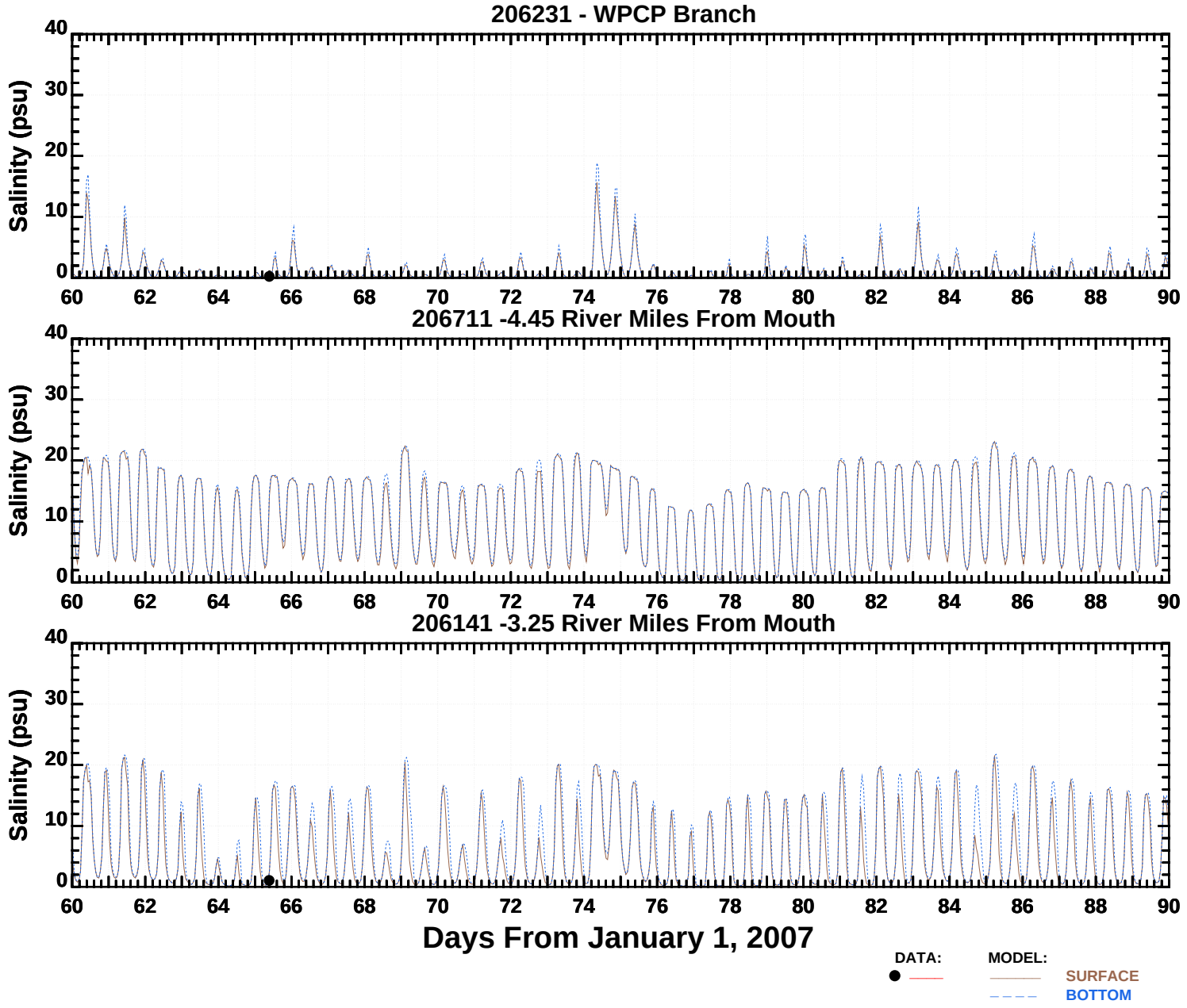

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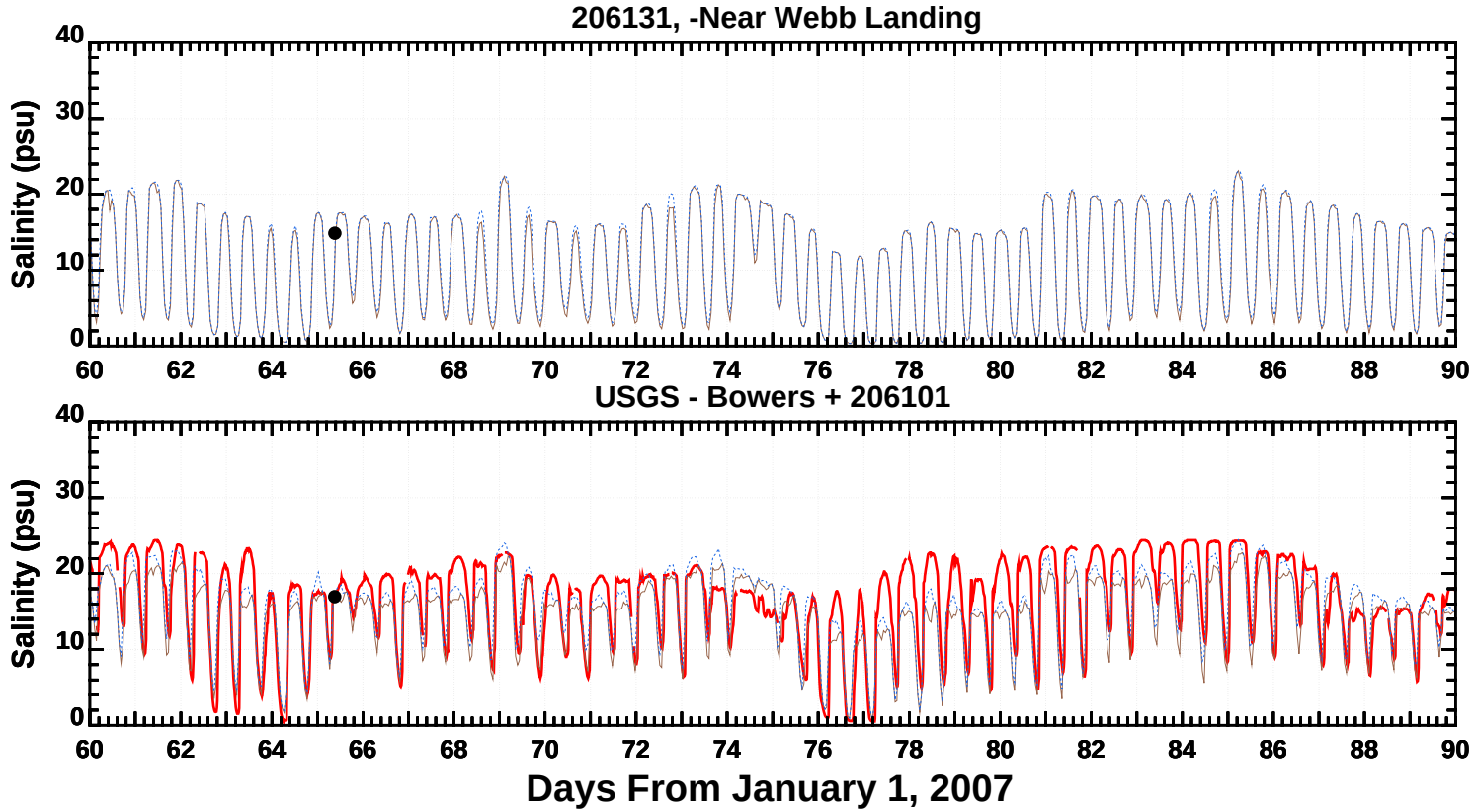
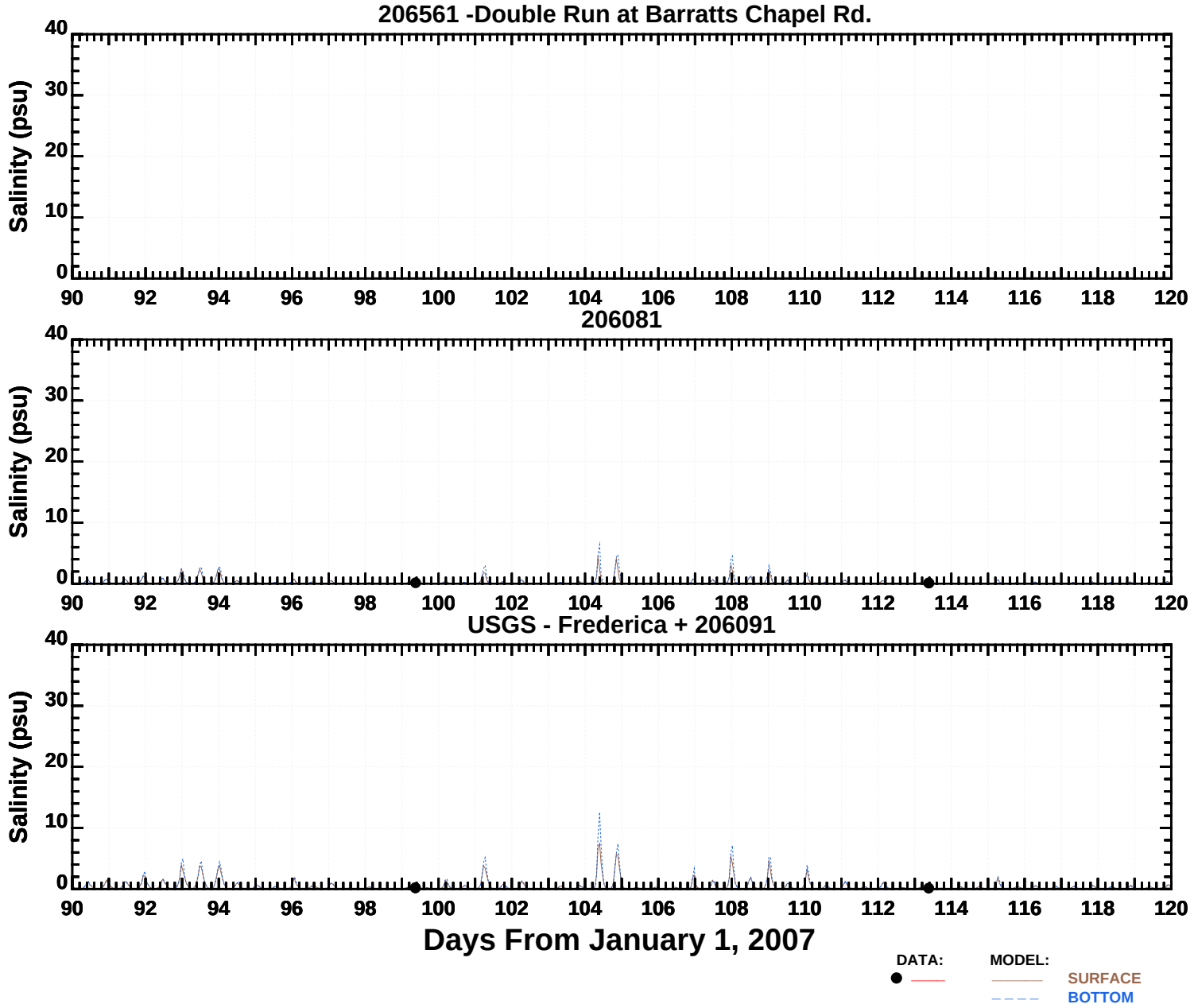
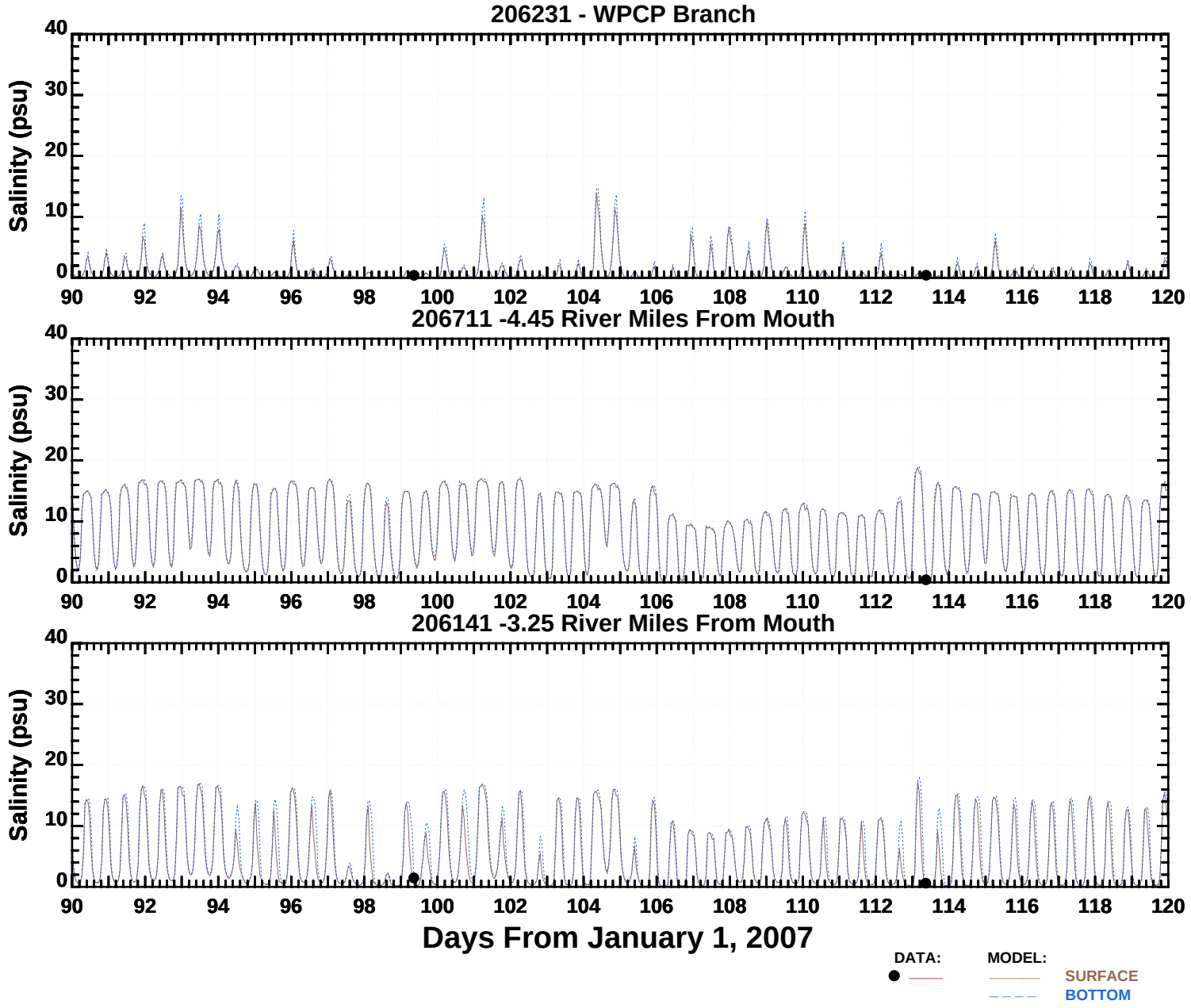


DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM


206561 -Double Run at Barratts Chapel Rd.
Salinity (psu)
0
10
20
30
40
90
92
94
96
98
100
102
104
106
108
110
112
114
116
118
120
206081
USGS - Frederica + 206091
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



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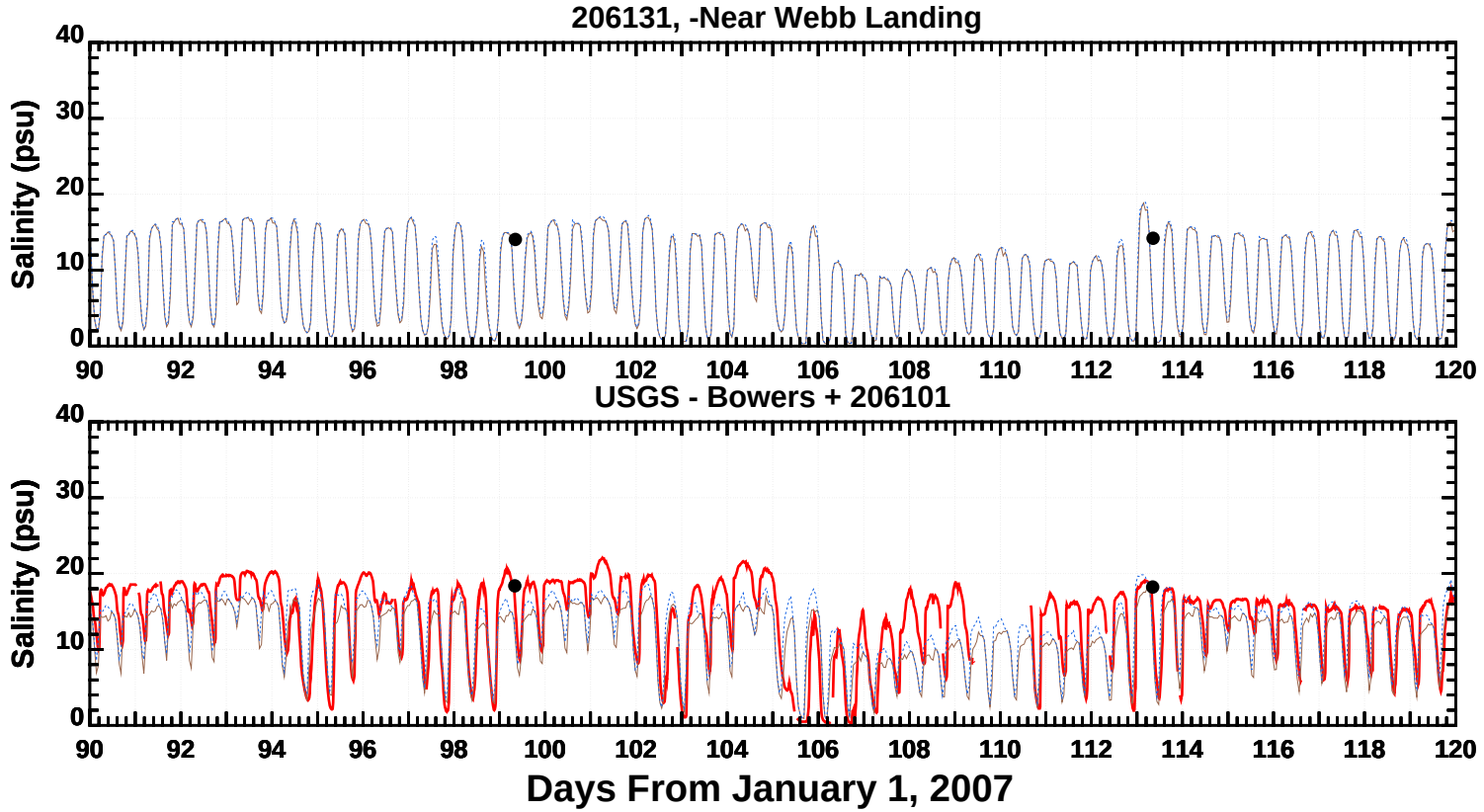
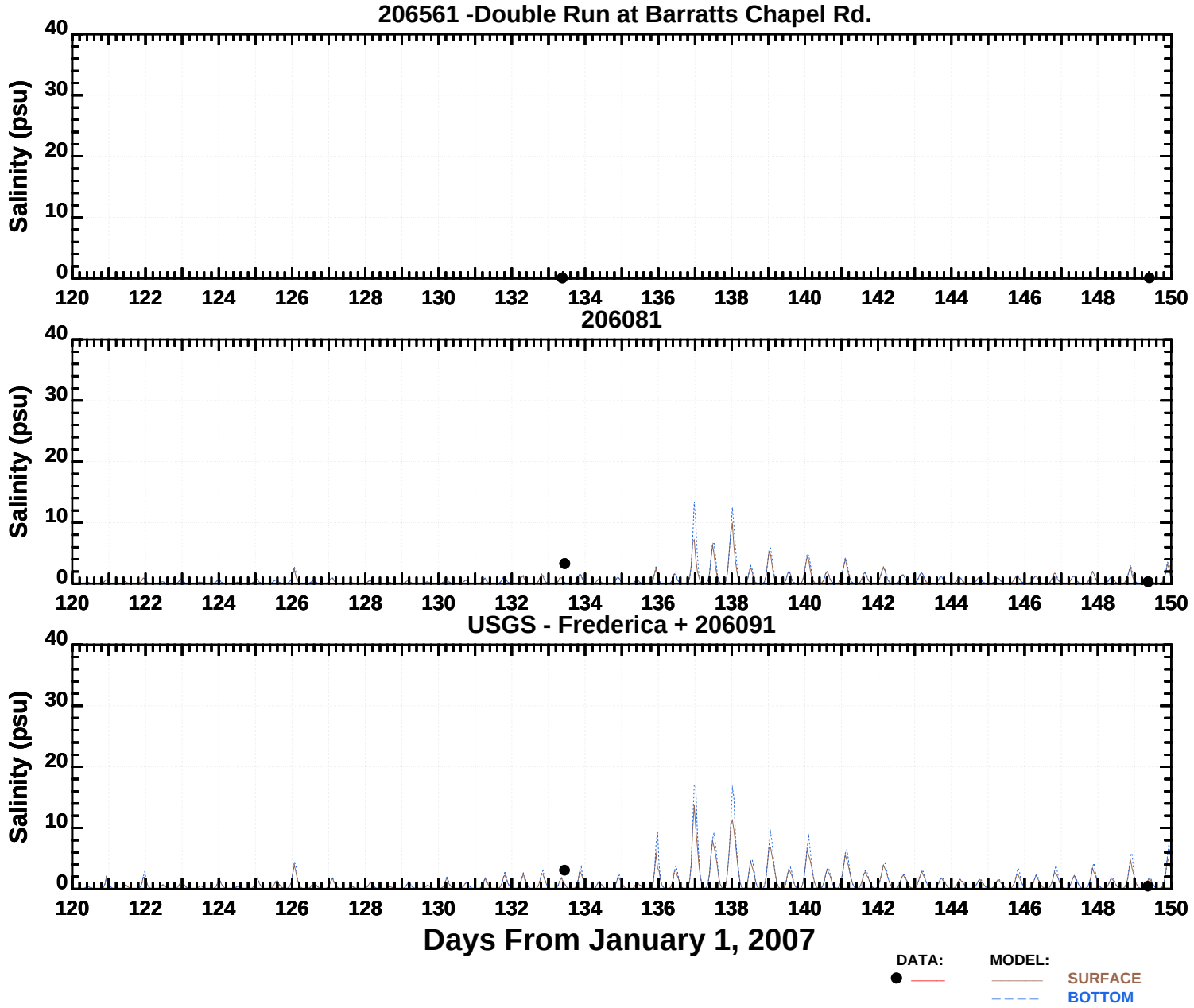


DATA: MODEL:
SURFACE
BOTTOM



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Page 1 of 3
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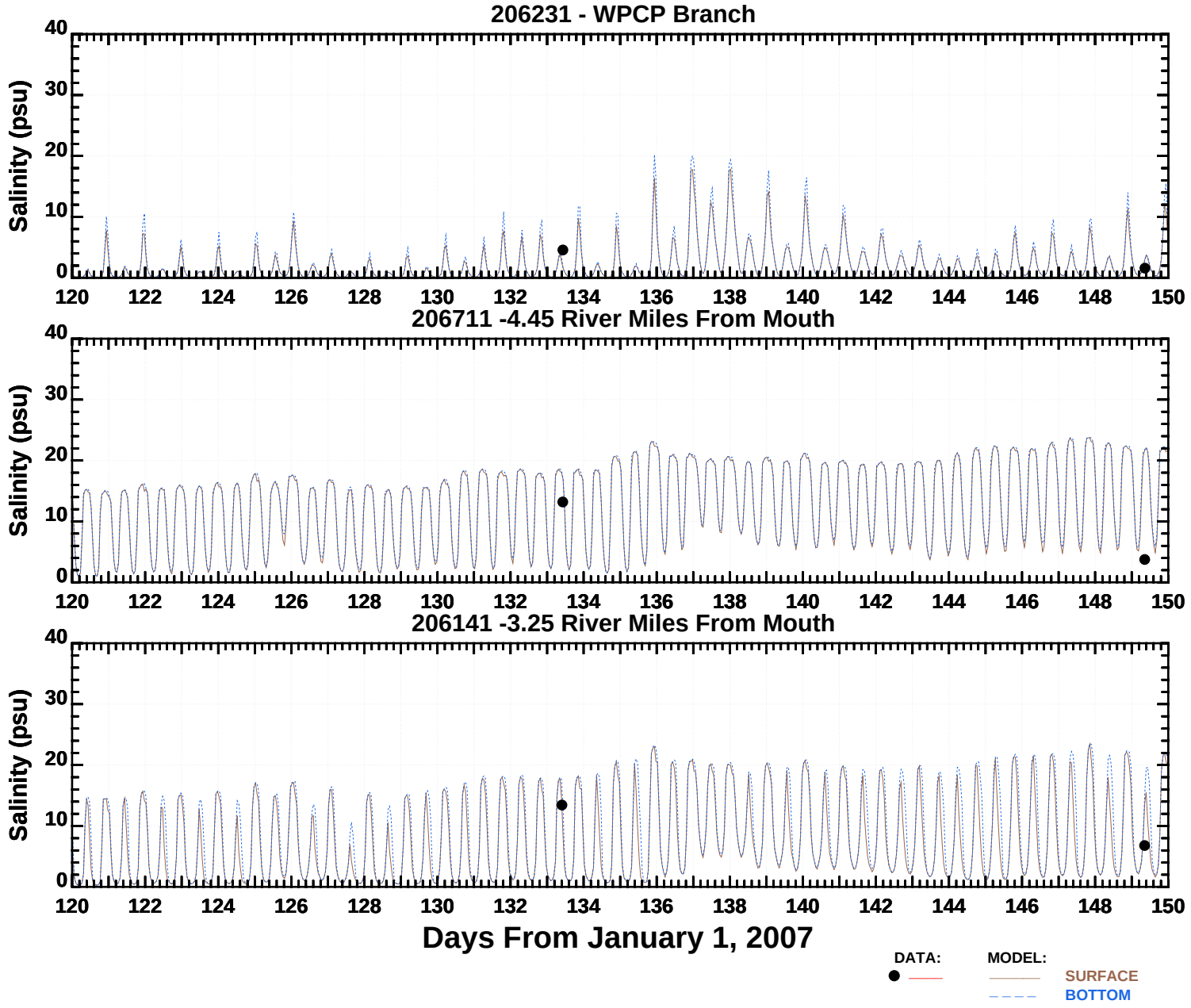

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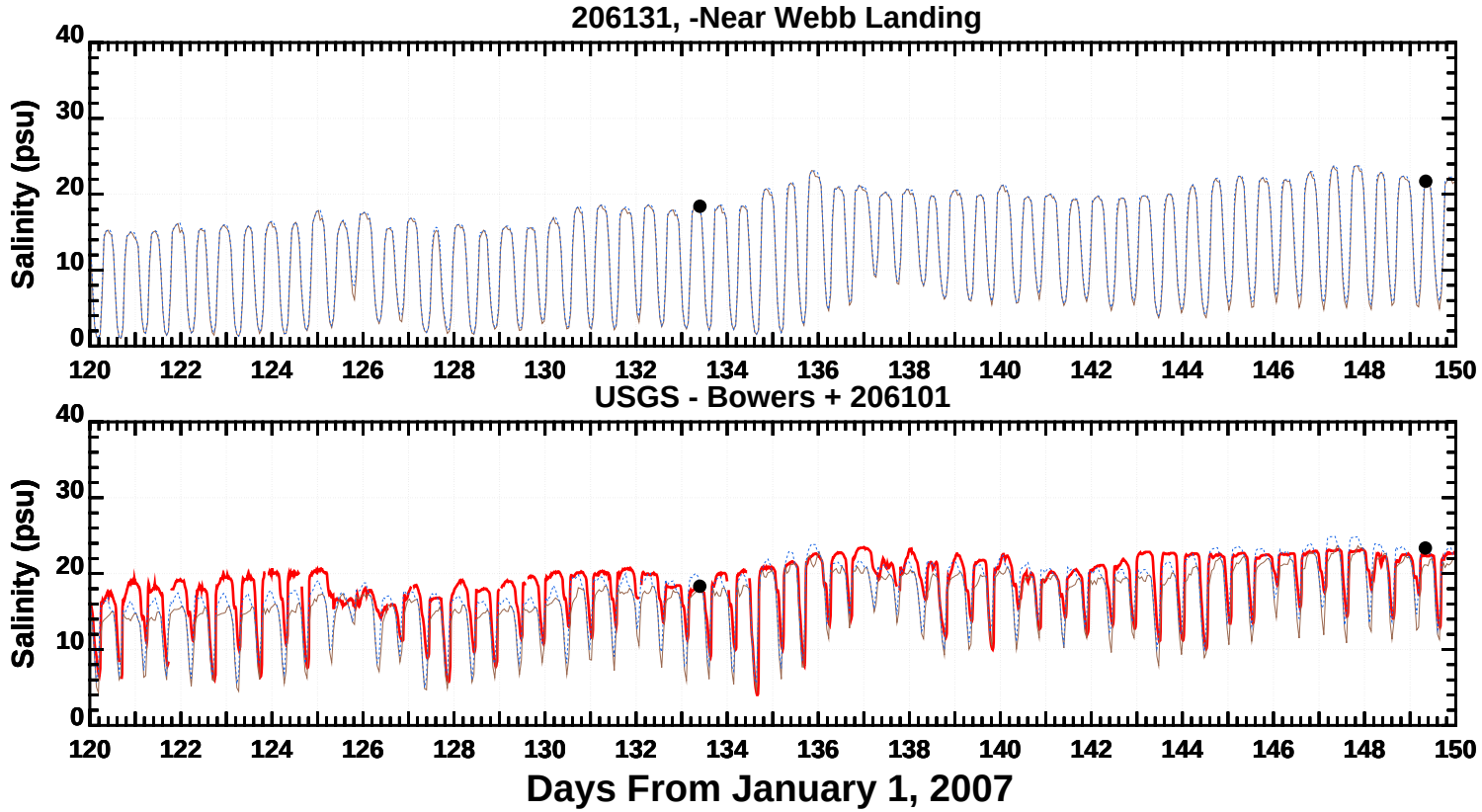
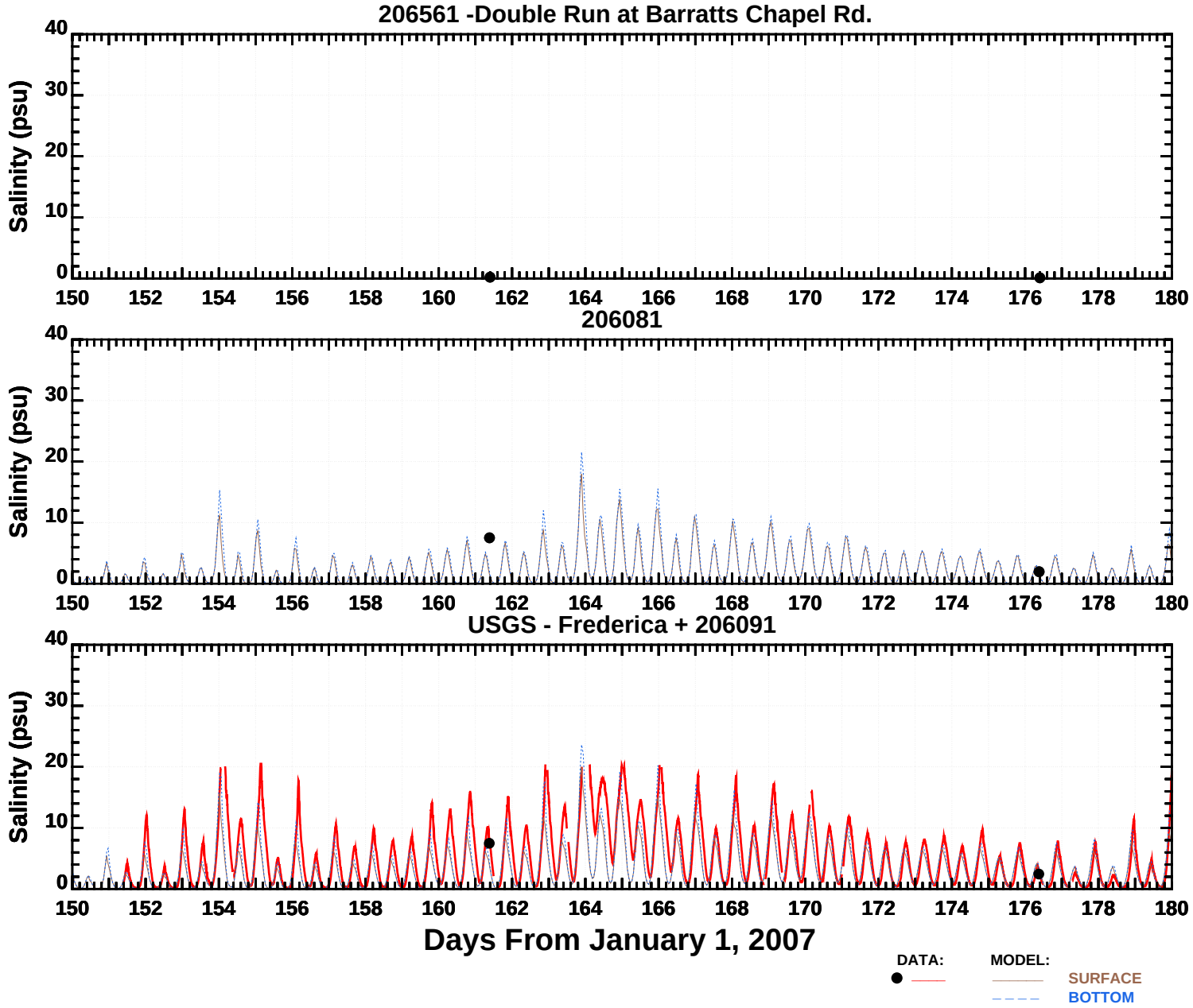
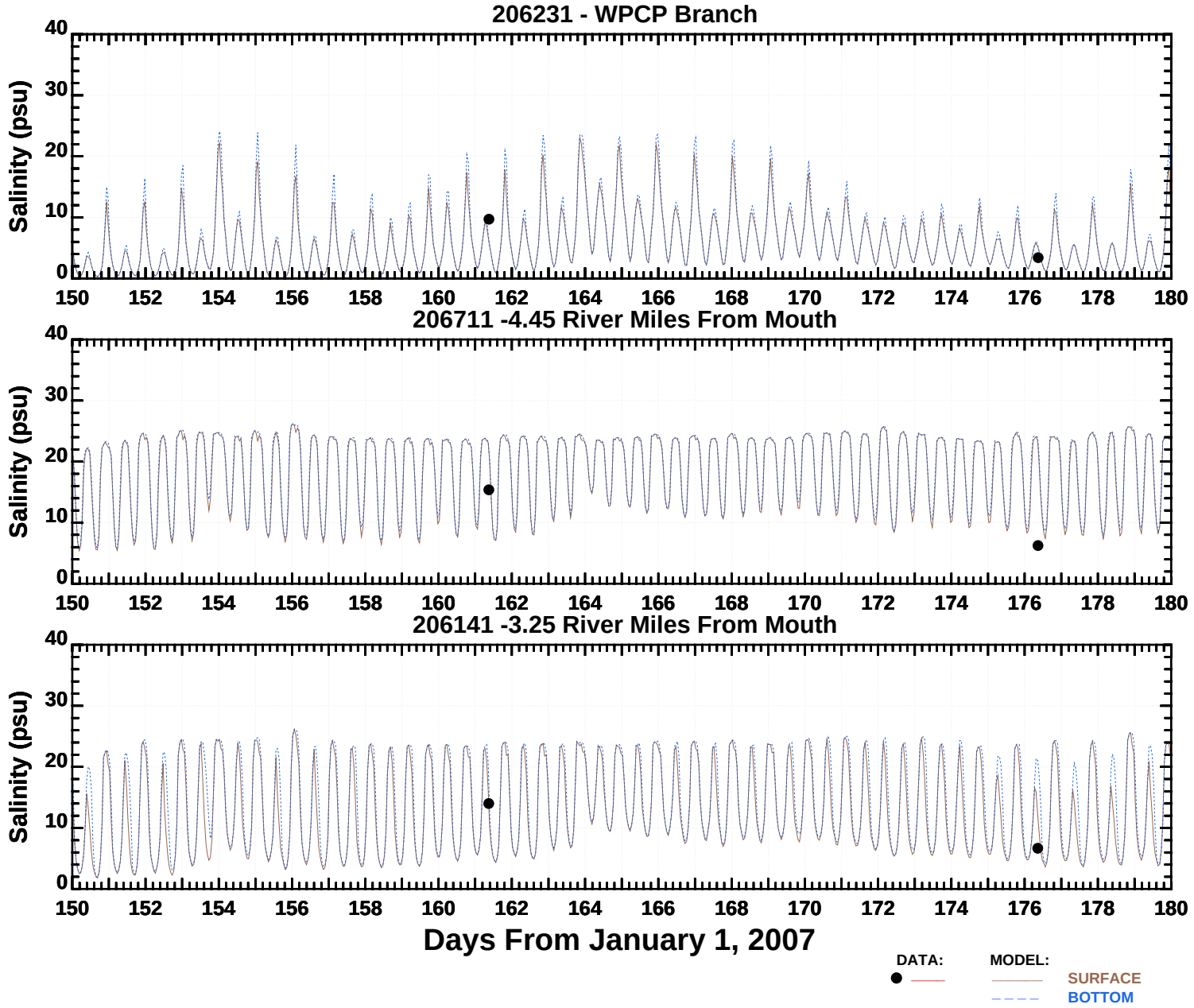


DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM


206561 -Double Run at Barratts Chapel Rd.
Salinity (psu)
0
10
20
30
40
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
206081
USGS - Frederica + 206091
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



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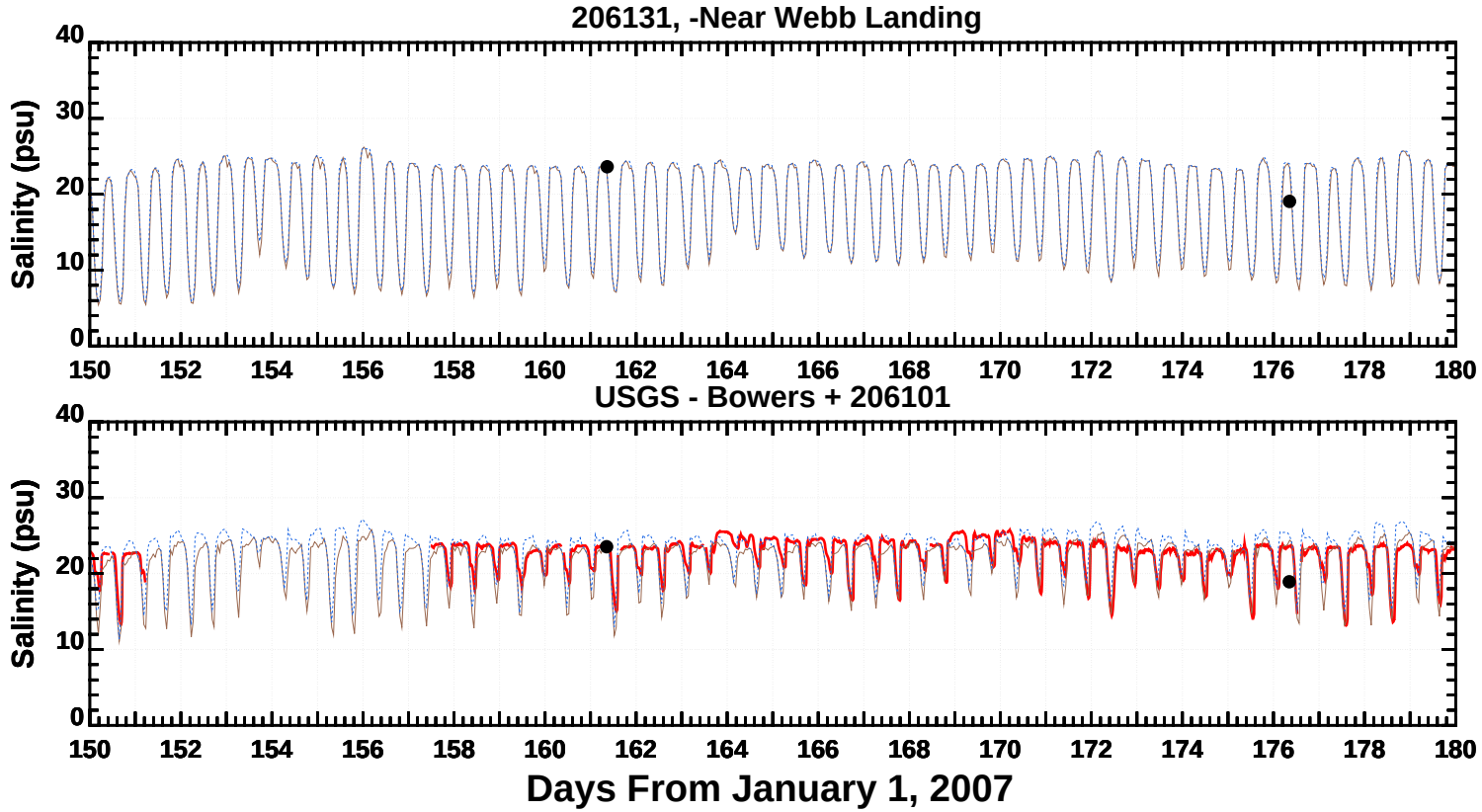
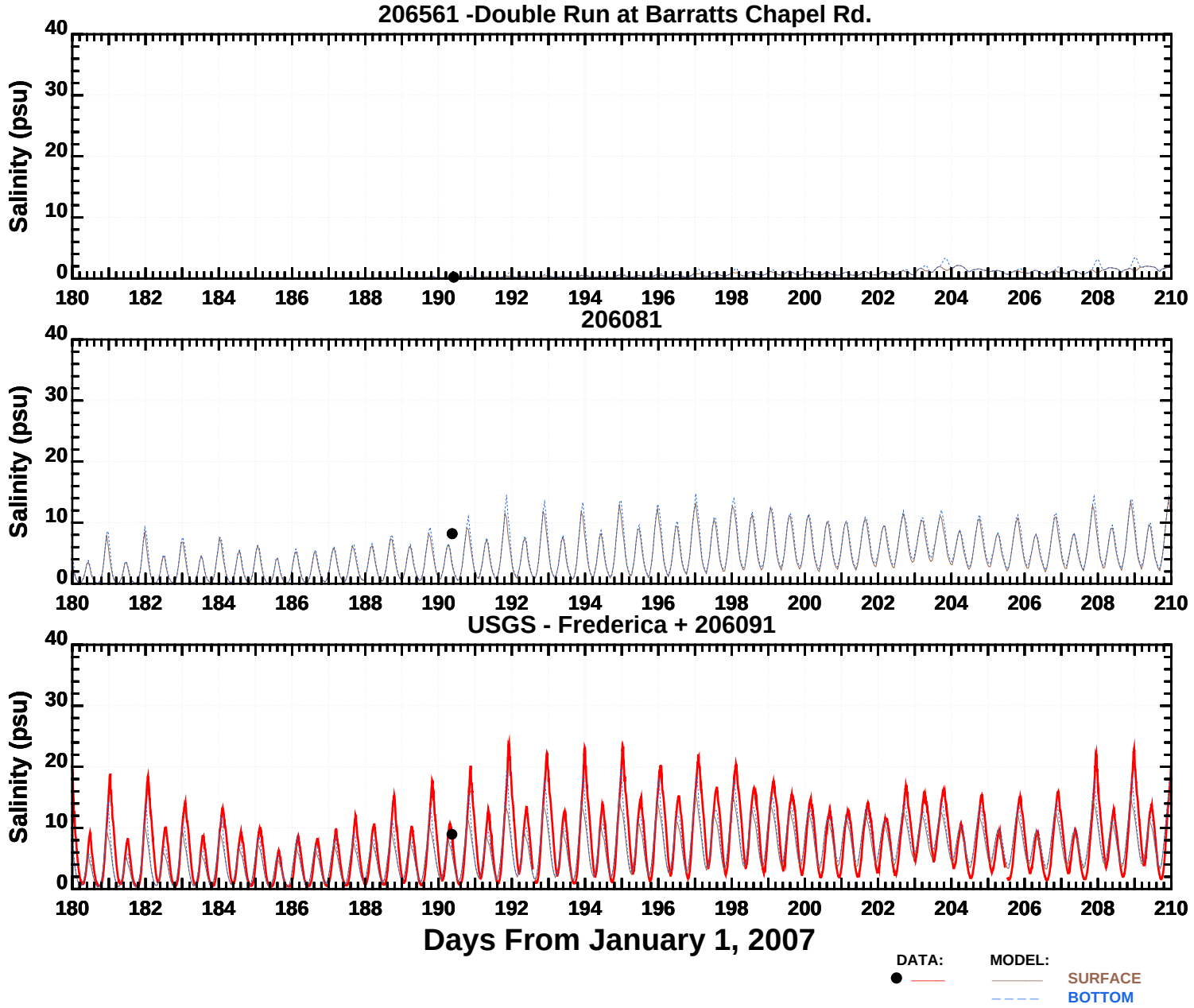


DATA: ● ——

MODEL: —— SURFACE

– – – – BOTTOM



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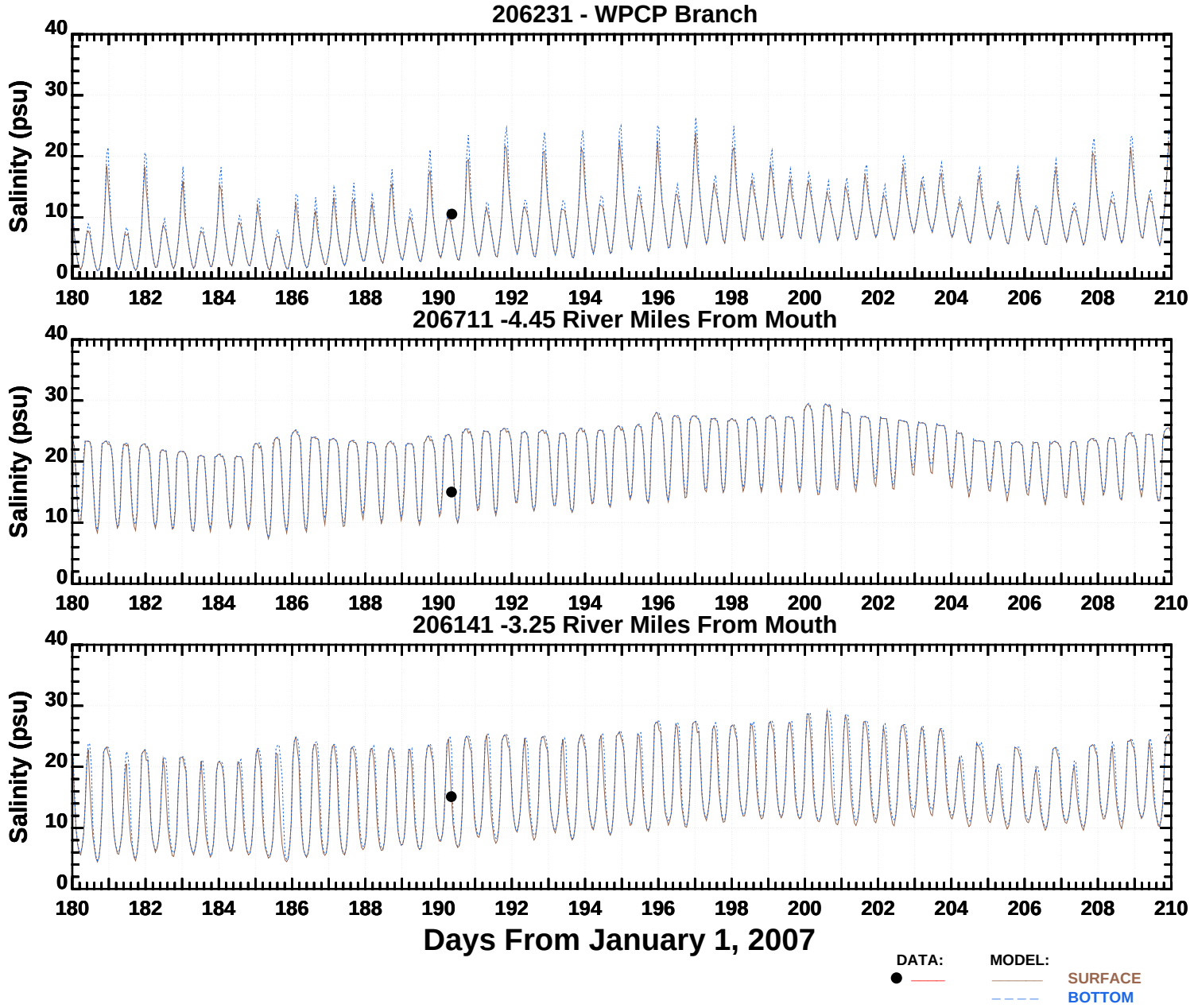
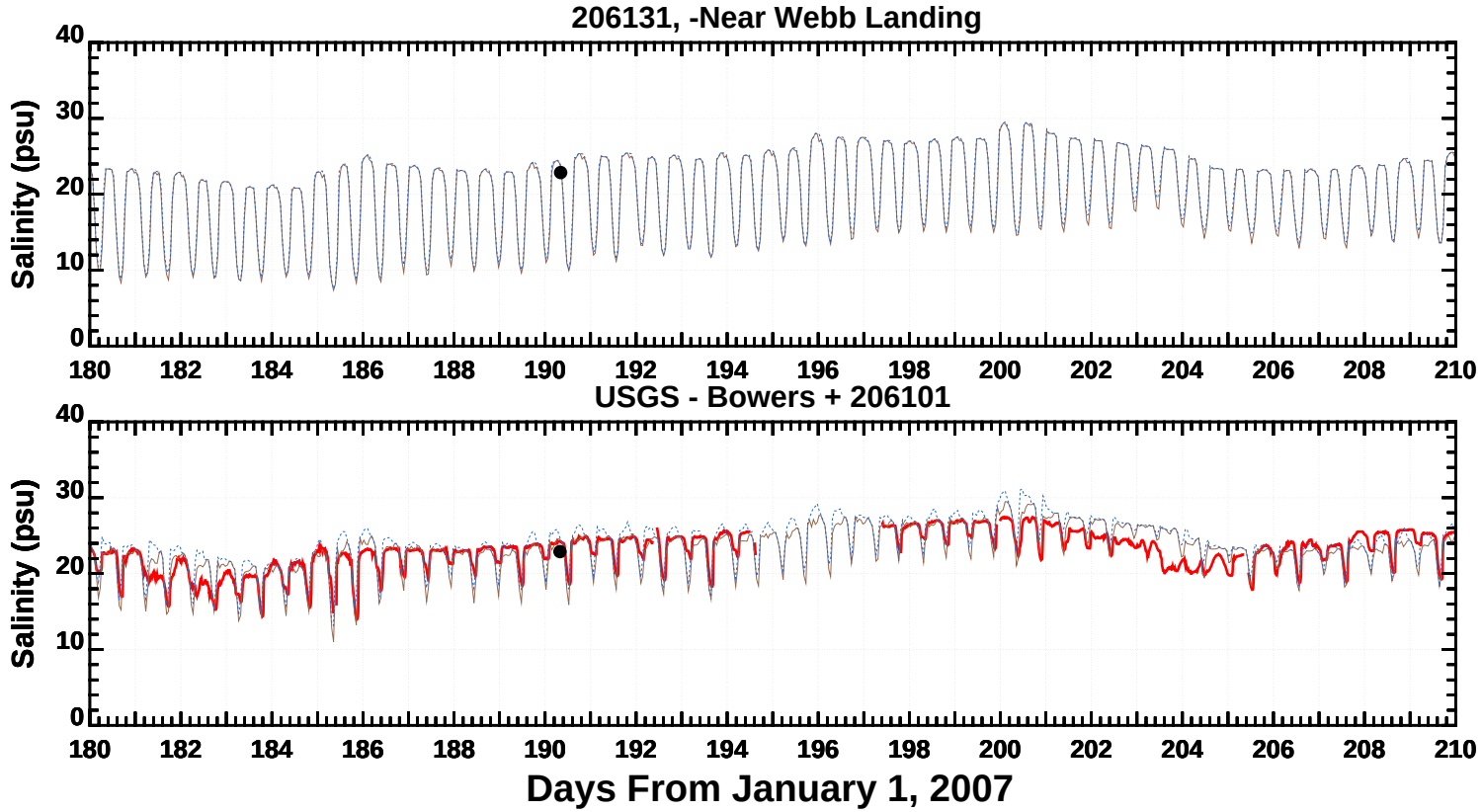
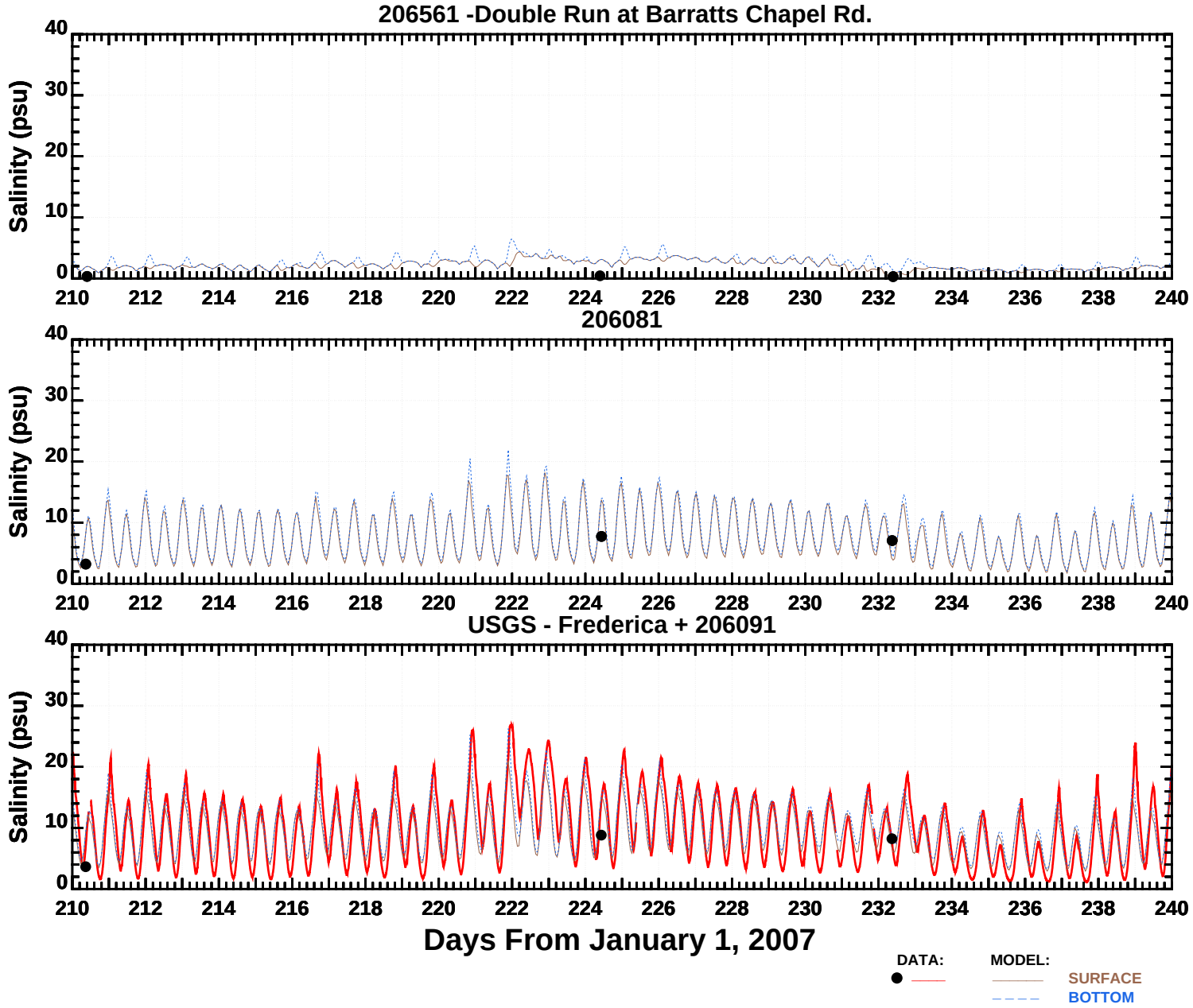

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM



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Page 1 of 3
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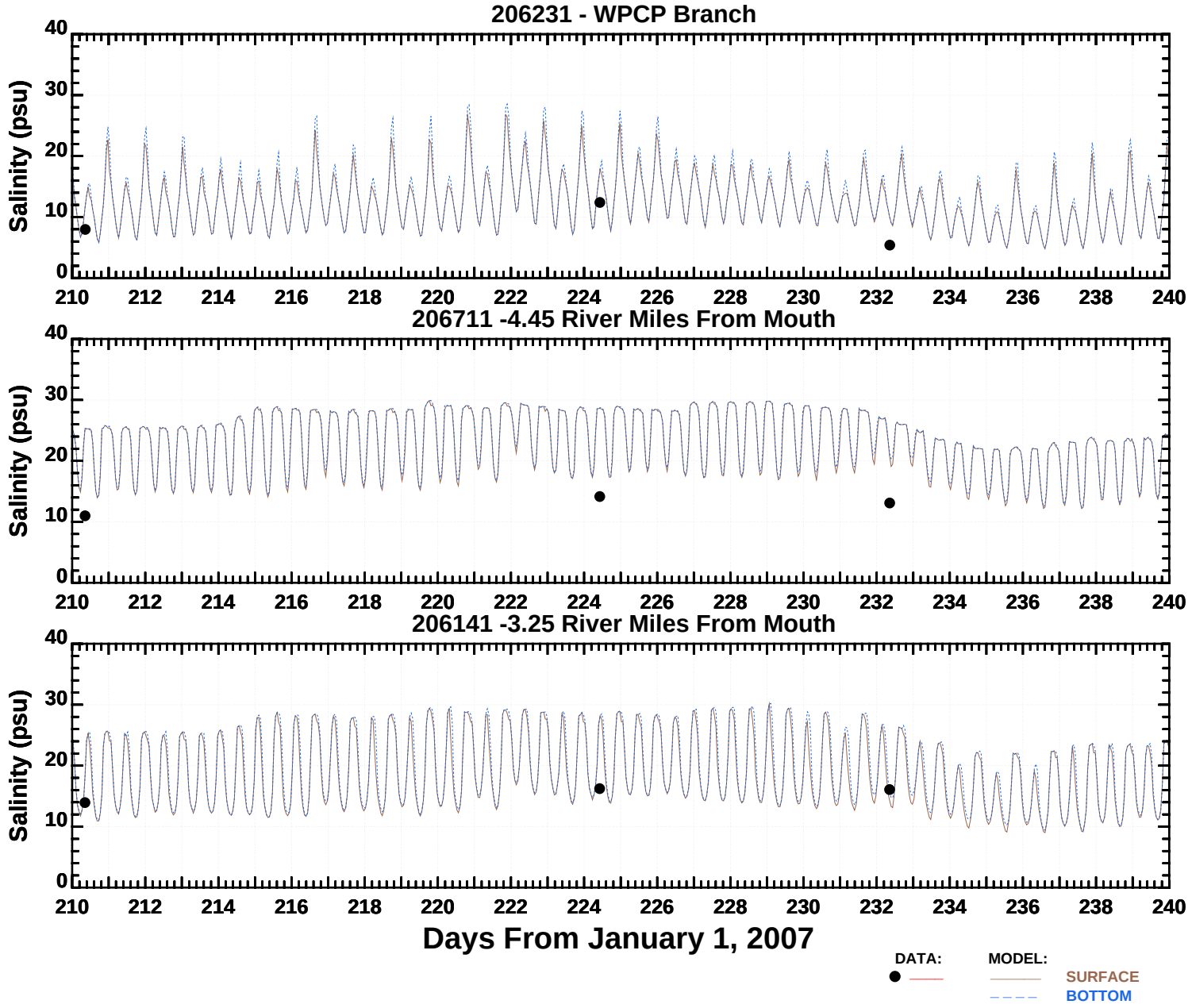
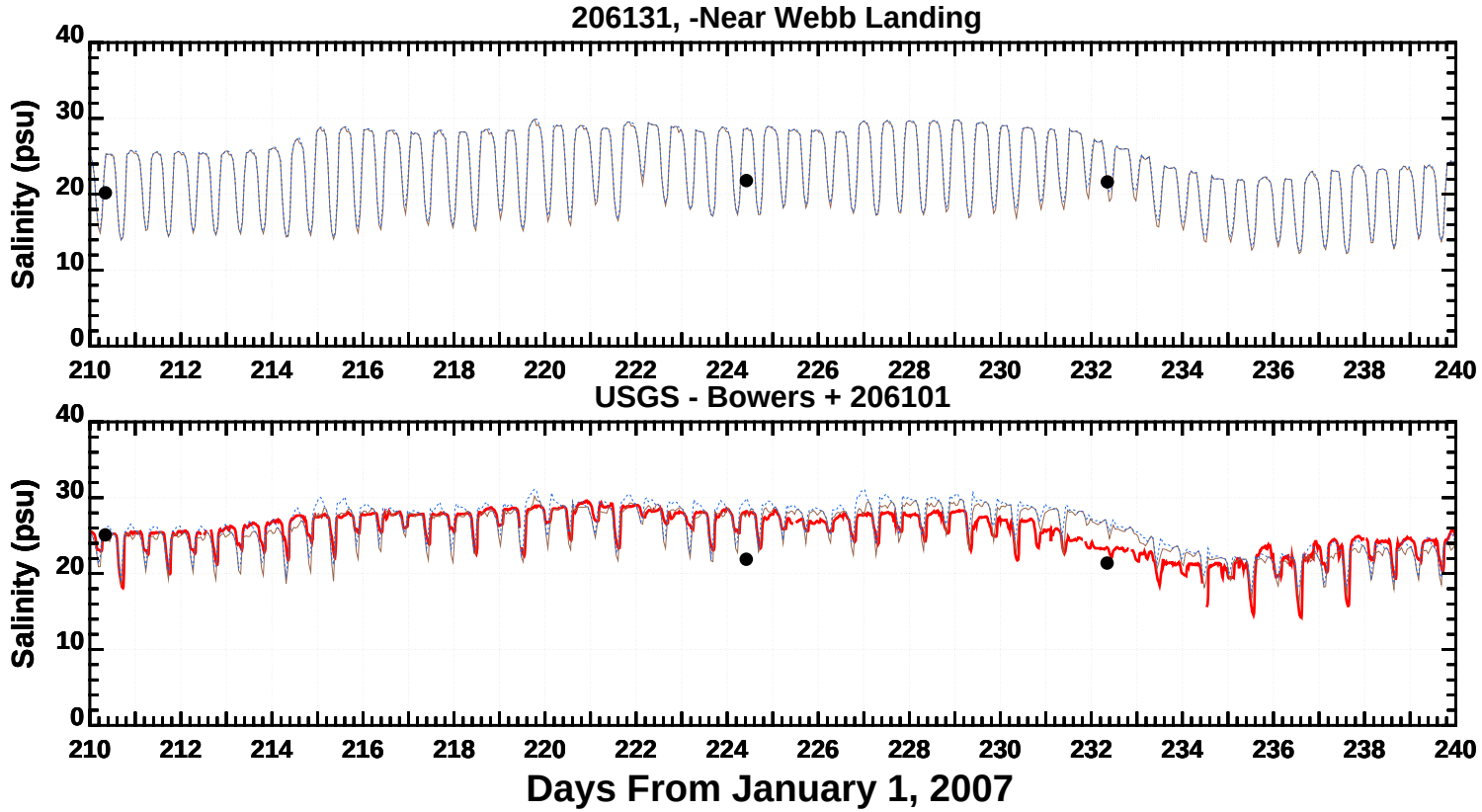
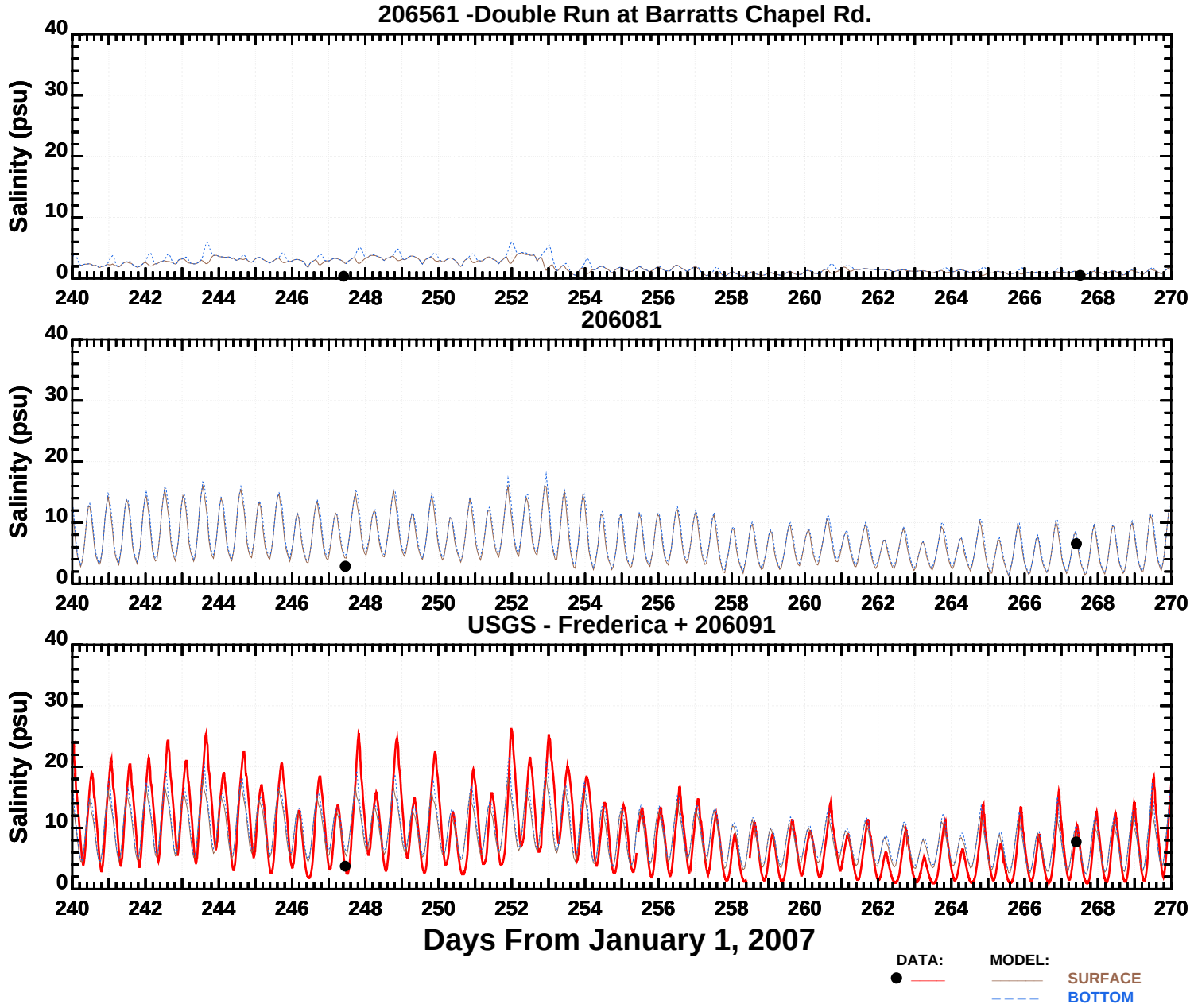
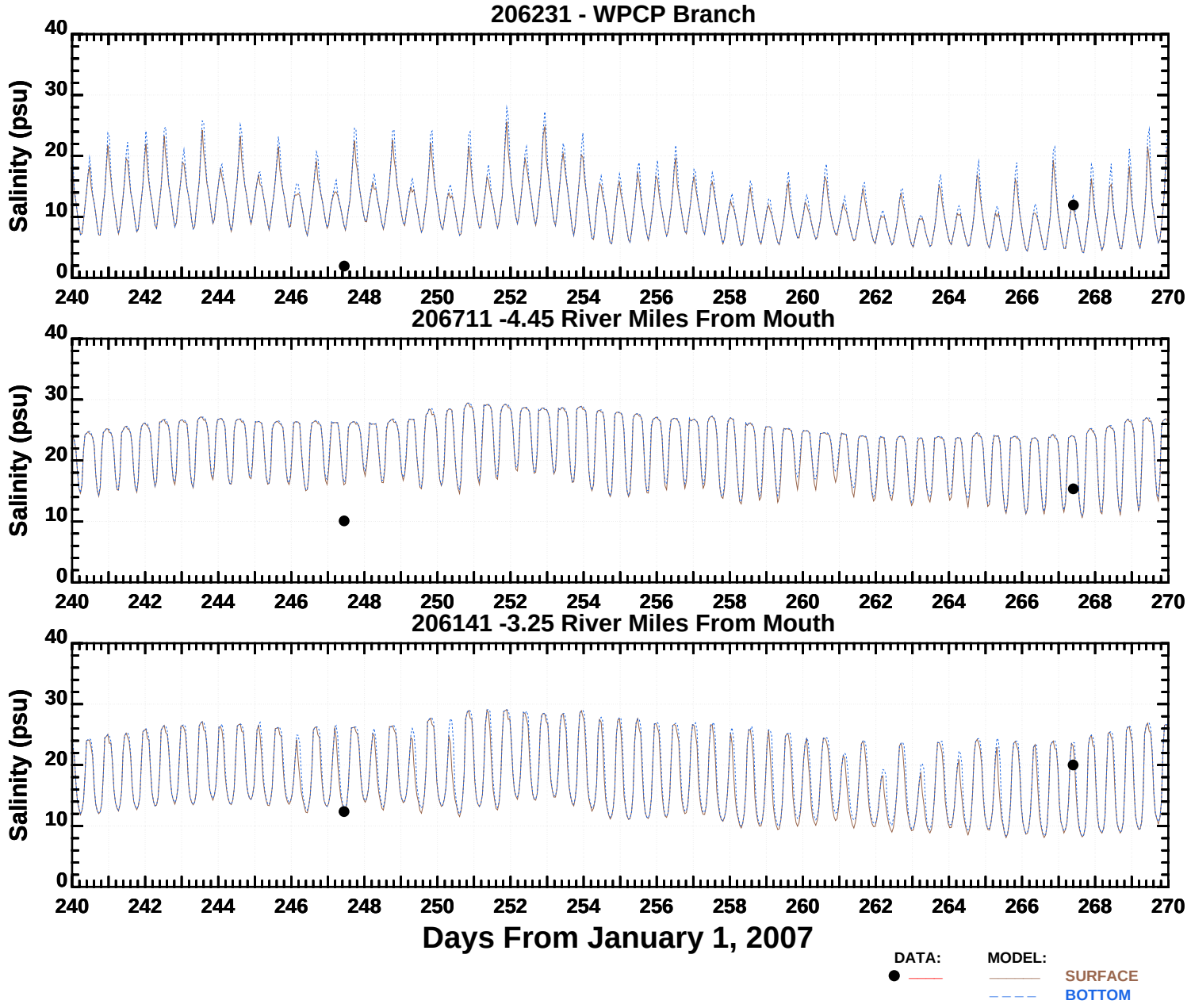
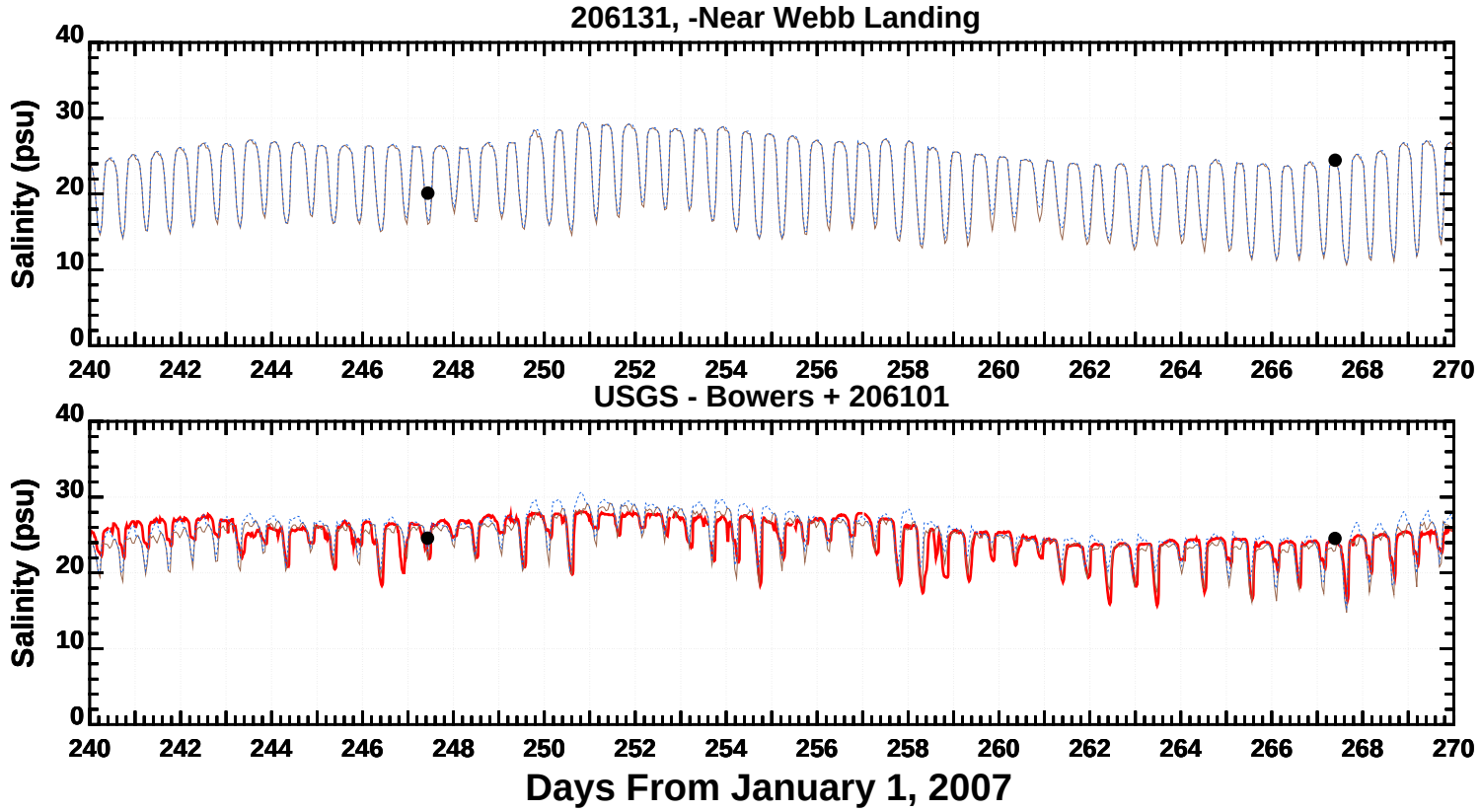

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



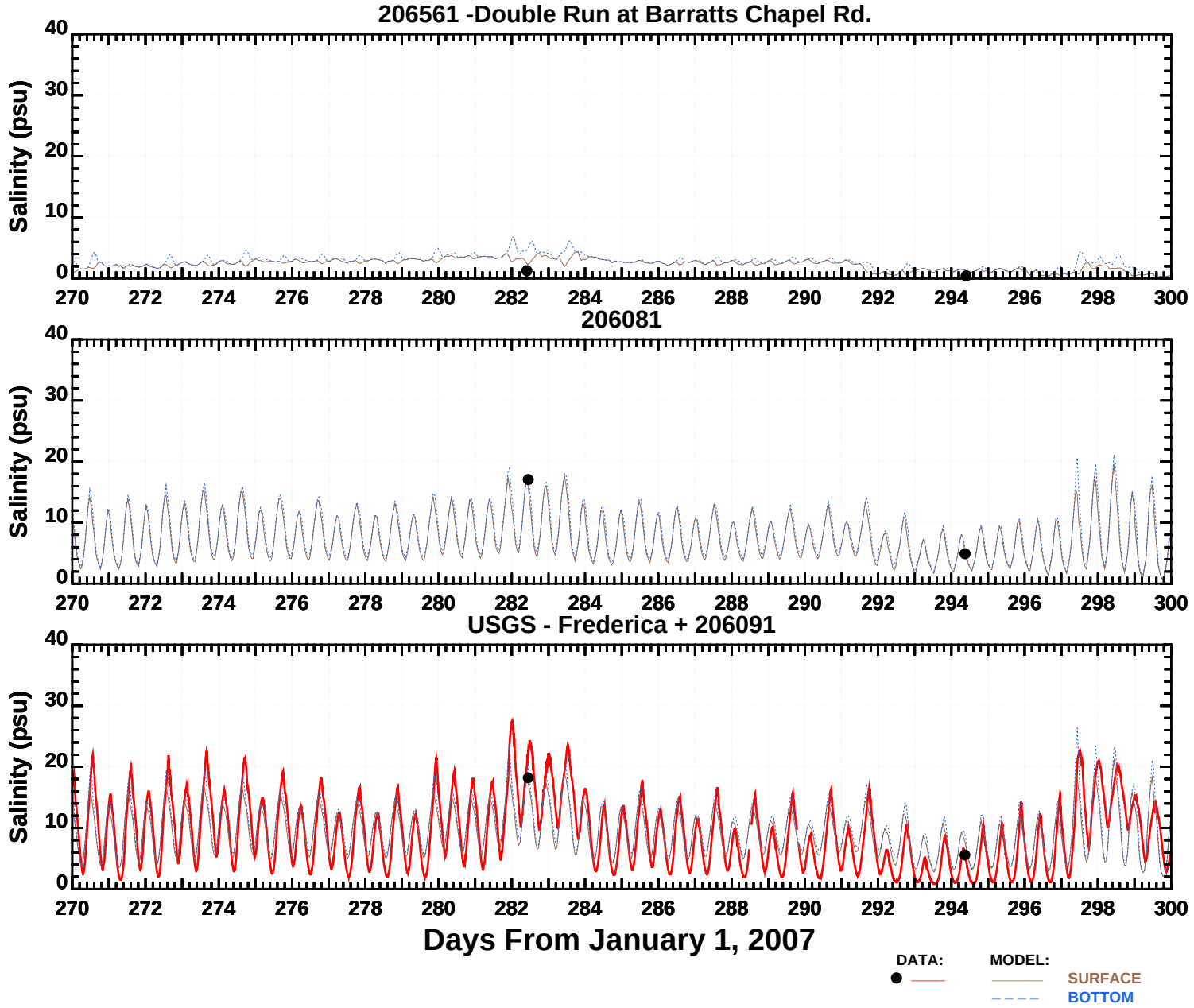
DATA: MODEL:
SURFACE
BOTTOM


206561 -Double Run at Barratts Chapel Rd.
Salinity (psu)
0
10
20
30
40
240
242
244
246
248
250
252
254
256
258
260
262
264
266
268
270
206081
Salinity (psu)
USGS - Frederica + 206091
Salinity (psu)
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
240
242
244
246
248
250
252
254
256
258
260
262
264
266
268
270
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: MODEL:
SURFACE
BOTTOM



DNREC Study
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Page 1 of 3
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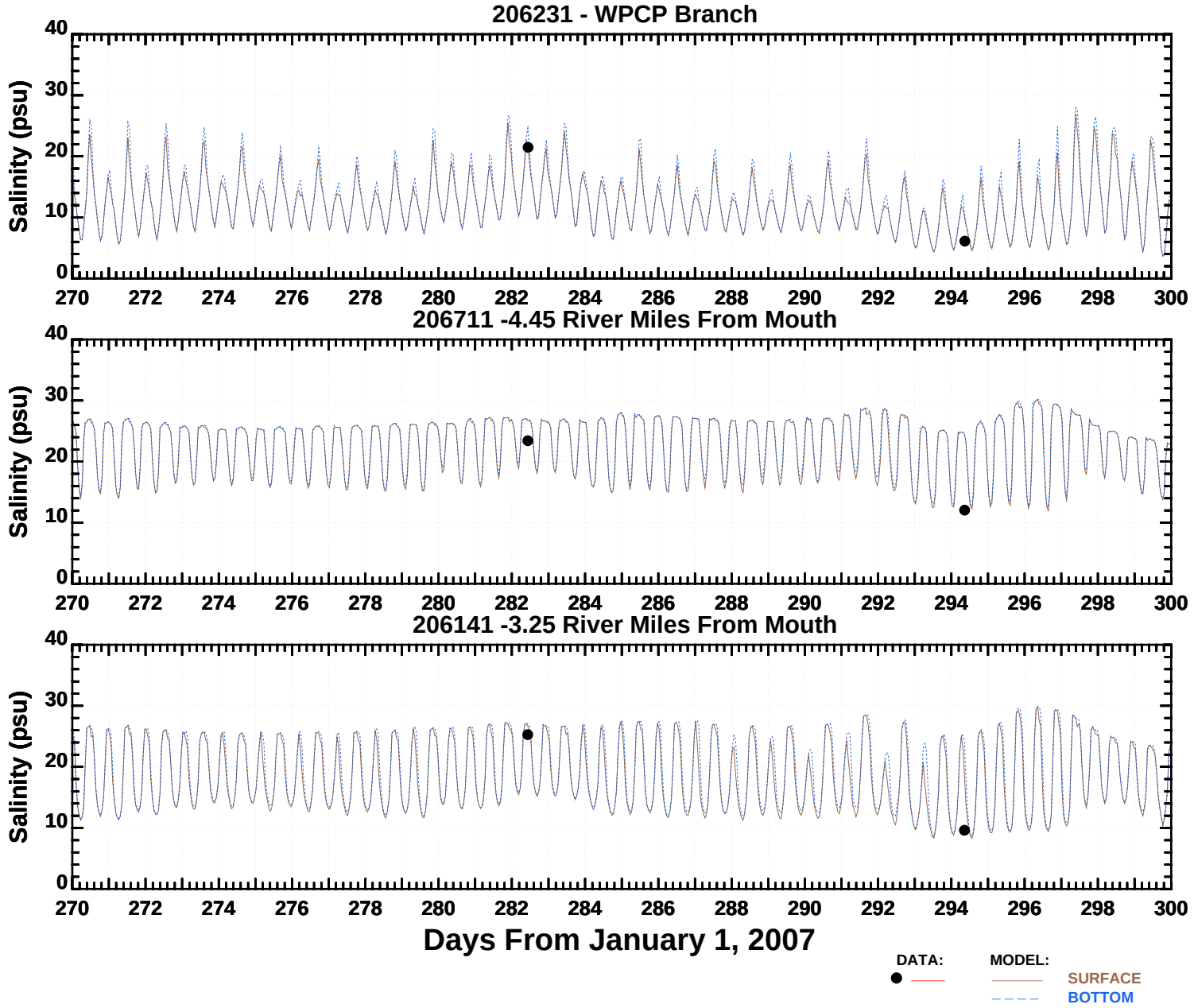
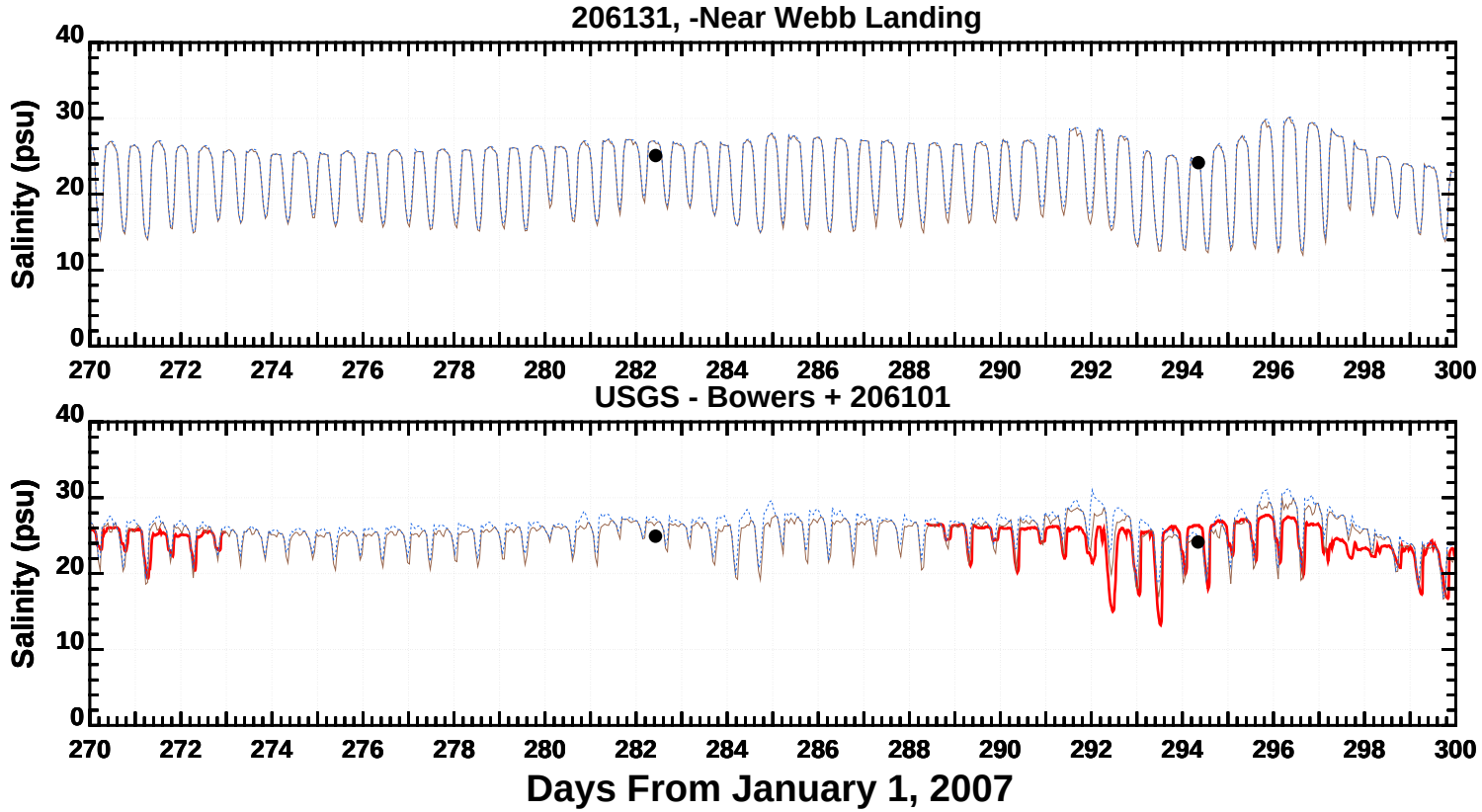
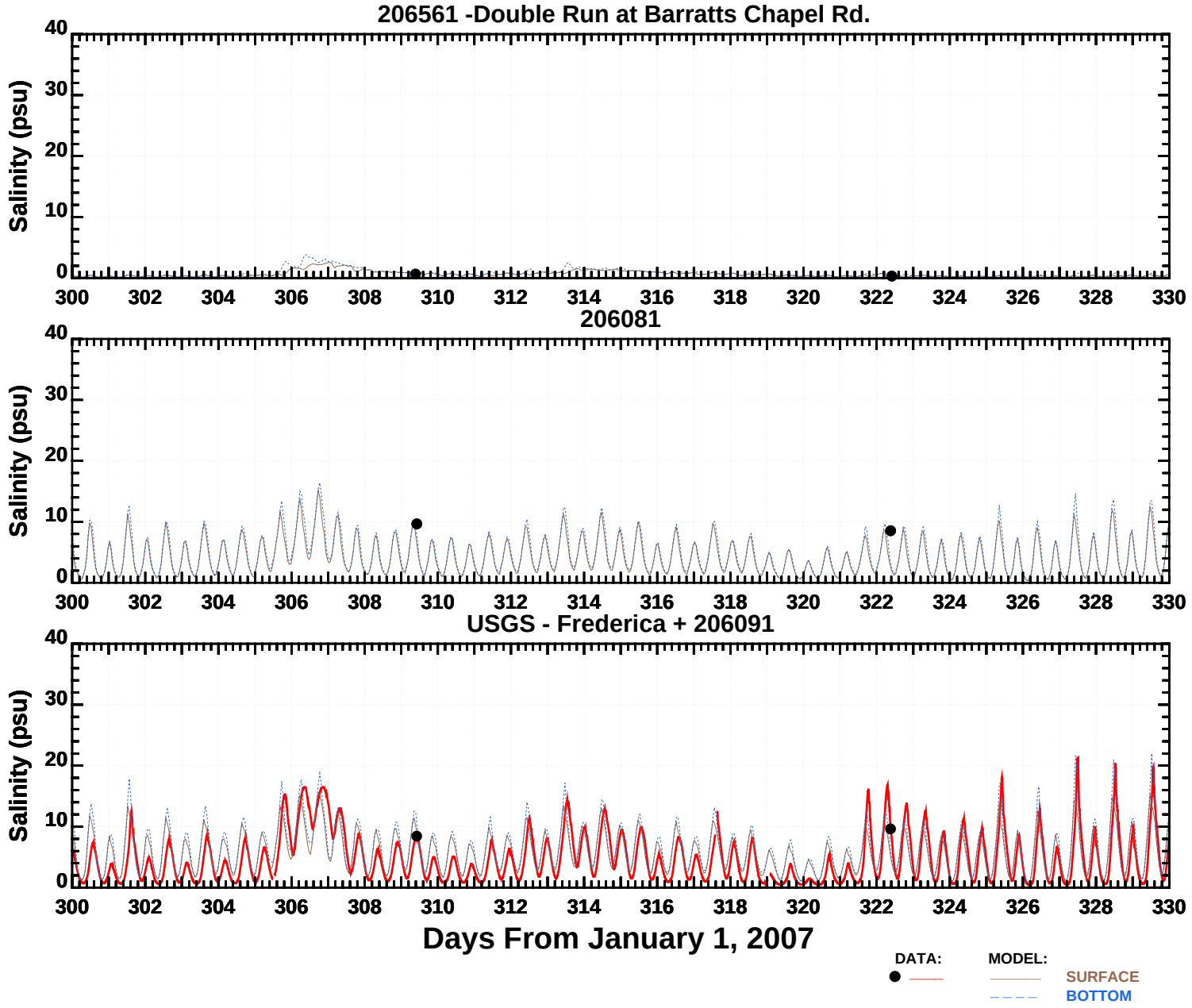

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
270
272
274
276
278
280
282
284
286
288
290
292
294
296
298
300
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● MODEL: SURFACE BOTTOM



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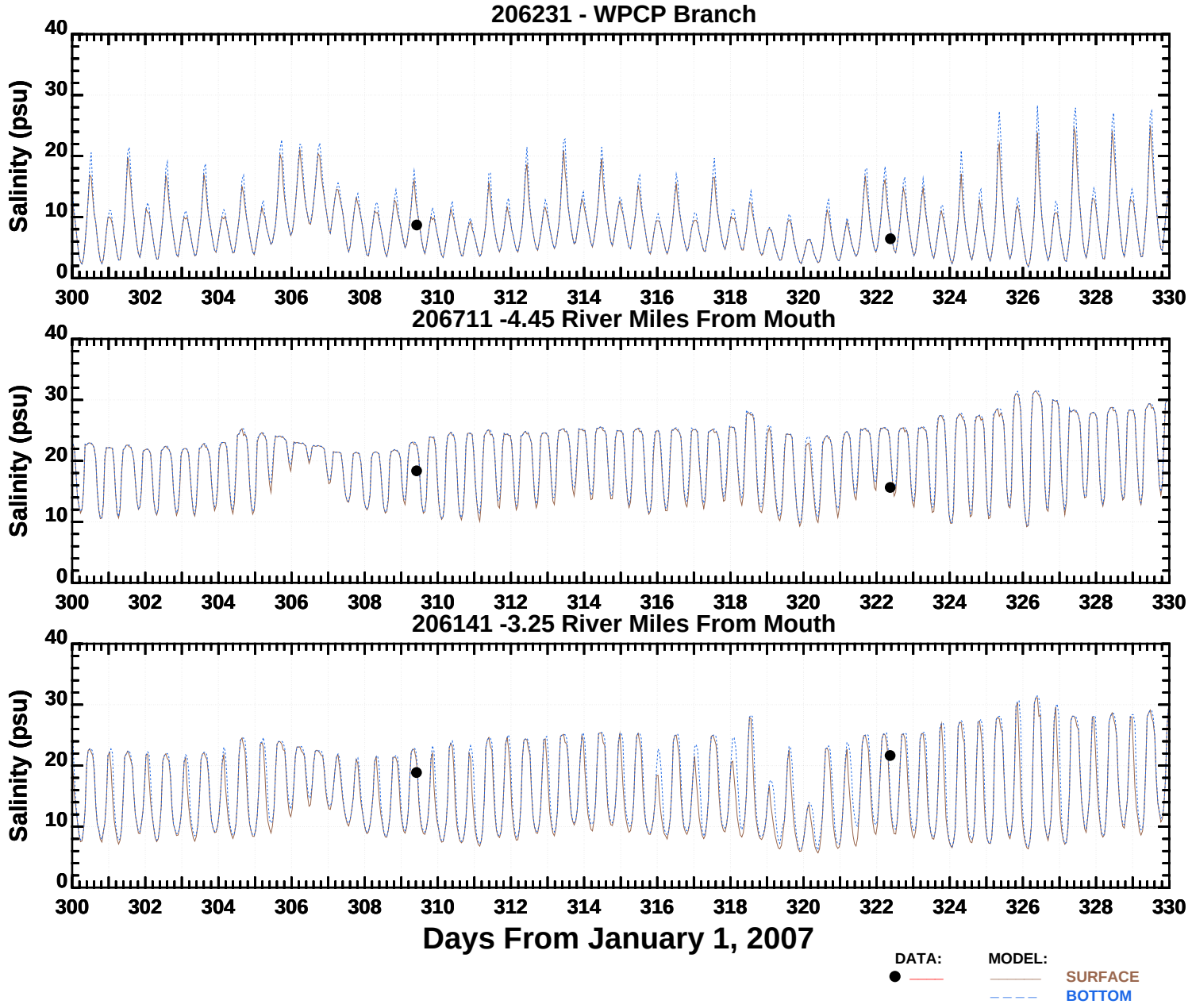
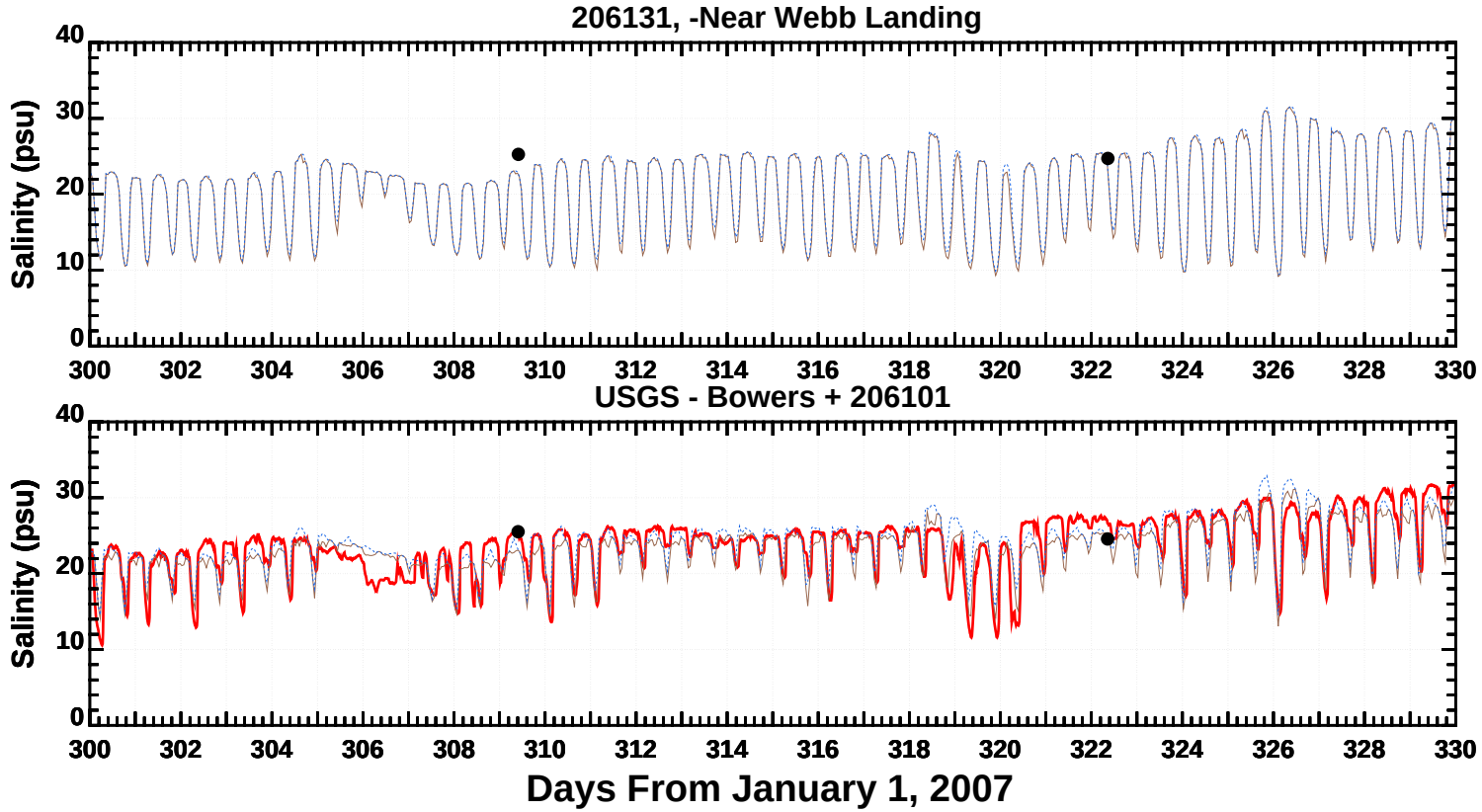

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
300
302
304
306
308
310
312
314
316
318
320
322
324
326
328
330
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: MODEL:

SURFACE

BOTTOM

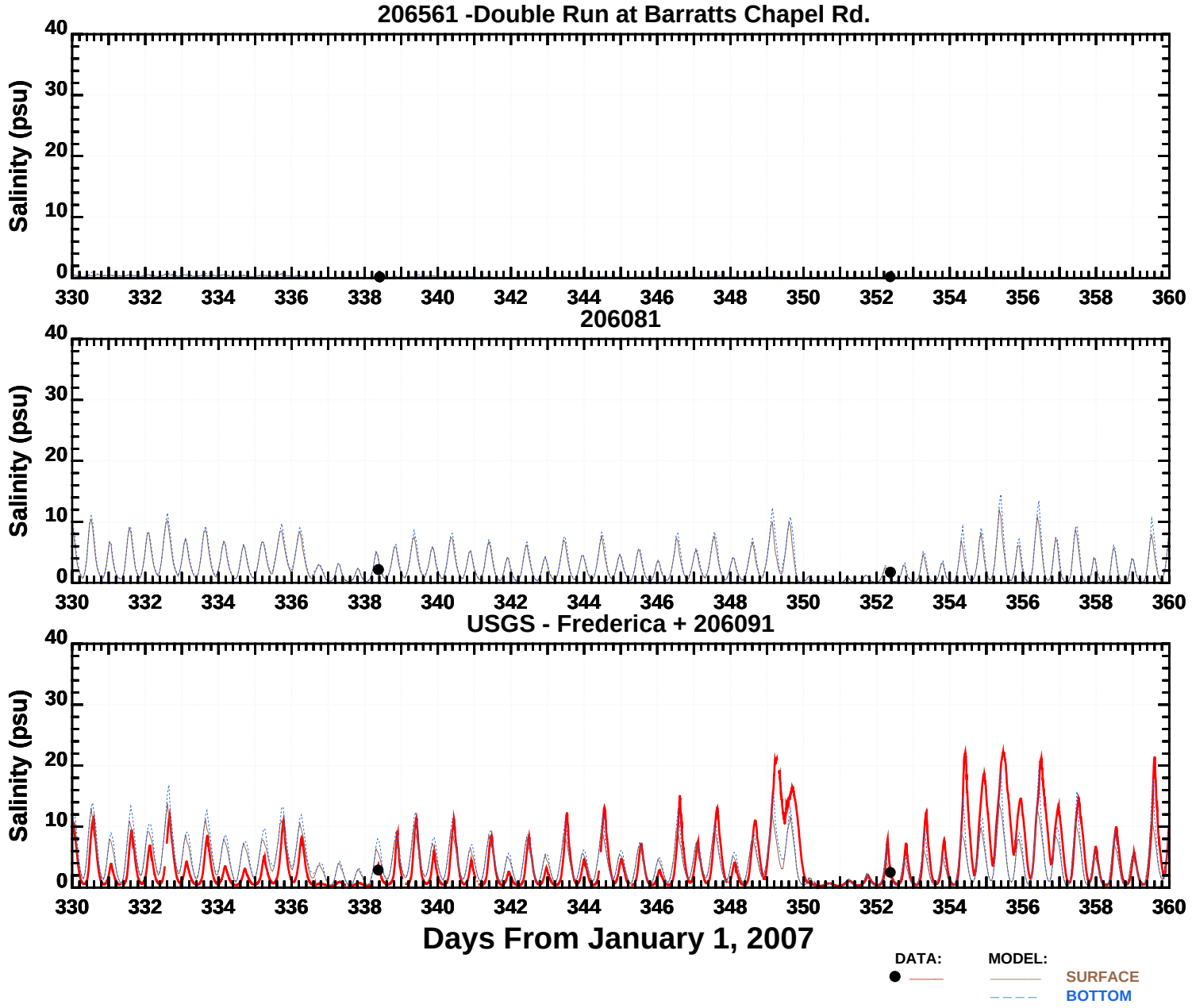
DNREC Study

/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp

Page 3 of 3

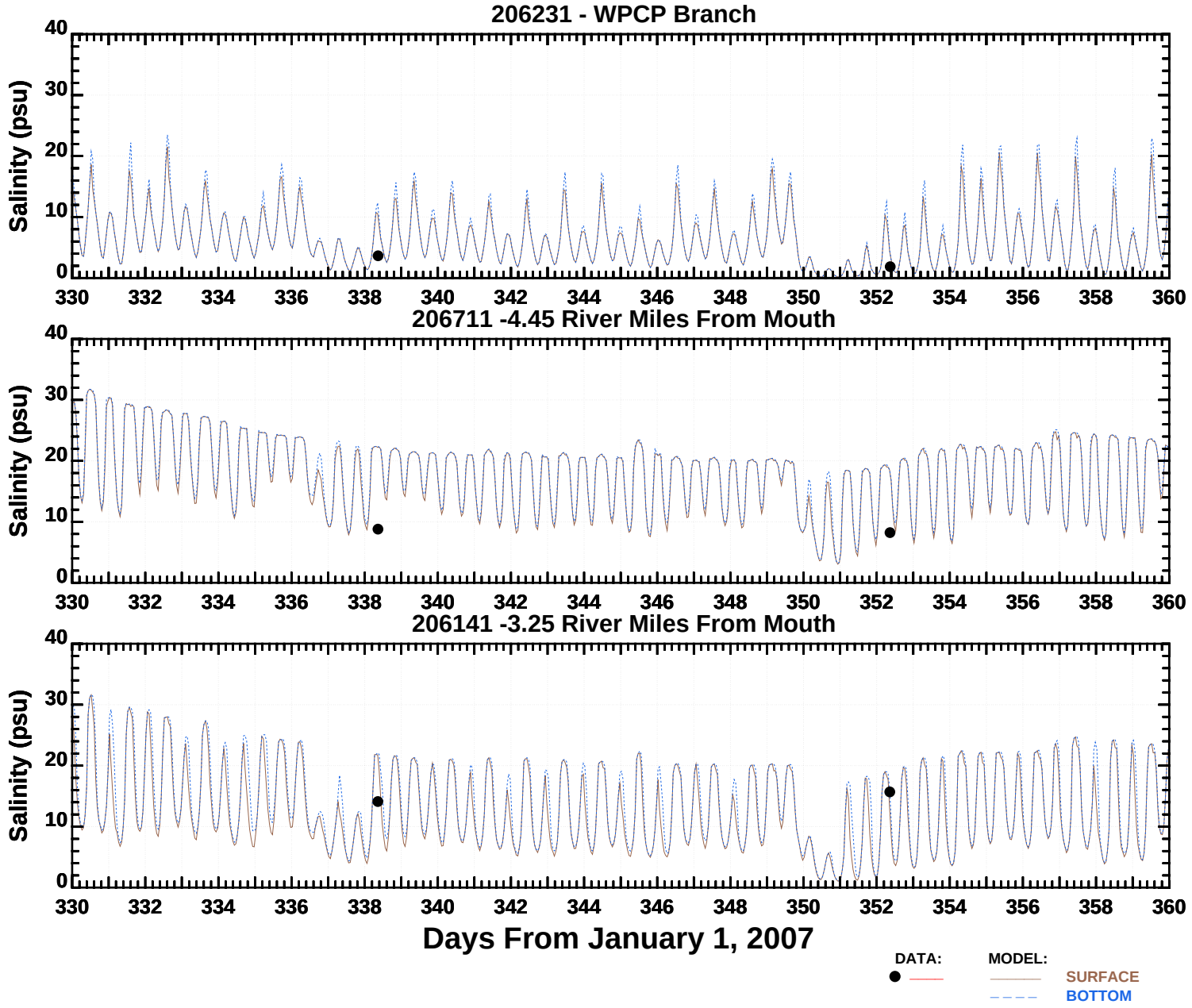
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

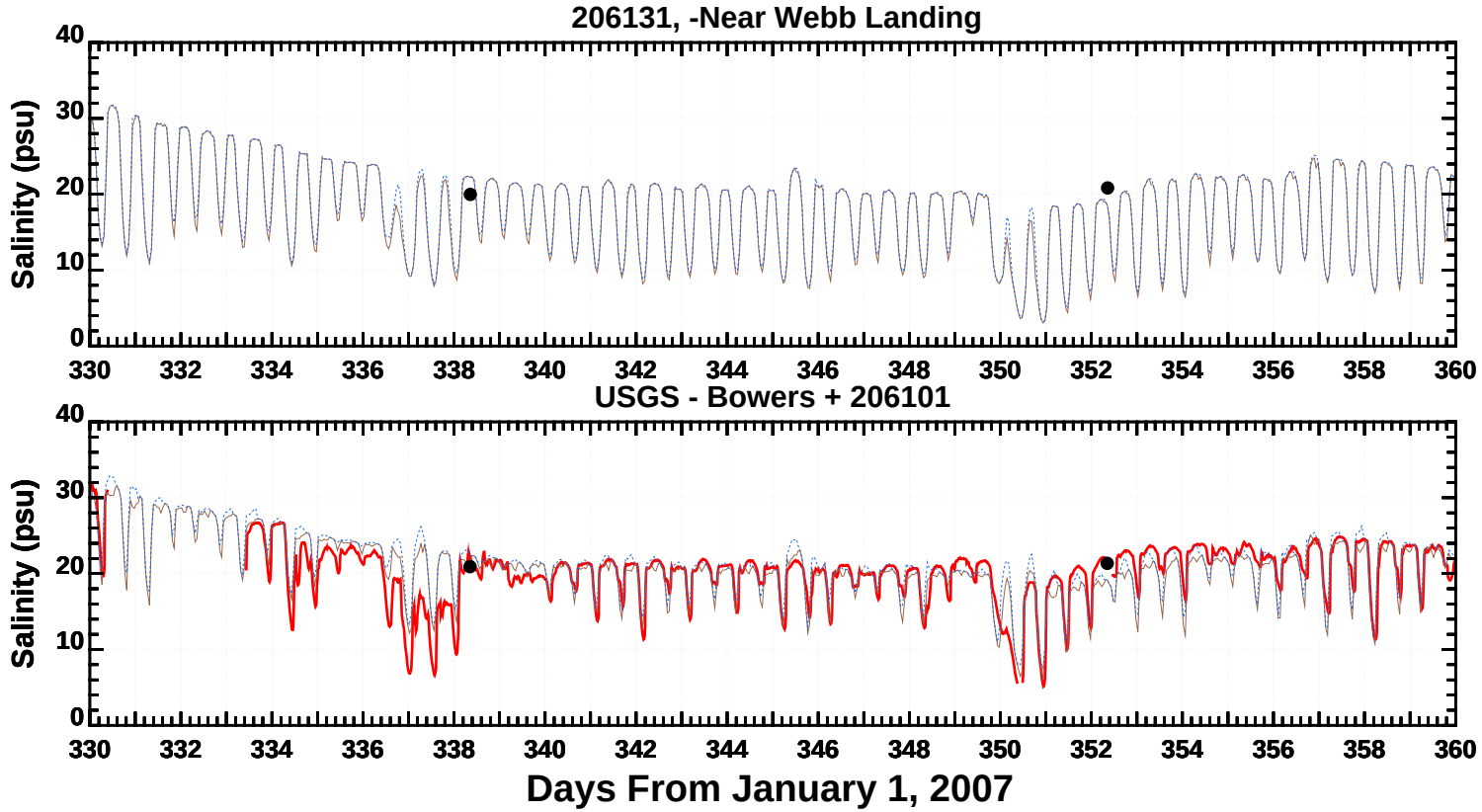
DATE: 1/22/2013 TIME: 13:12:13



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:12:21

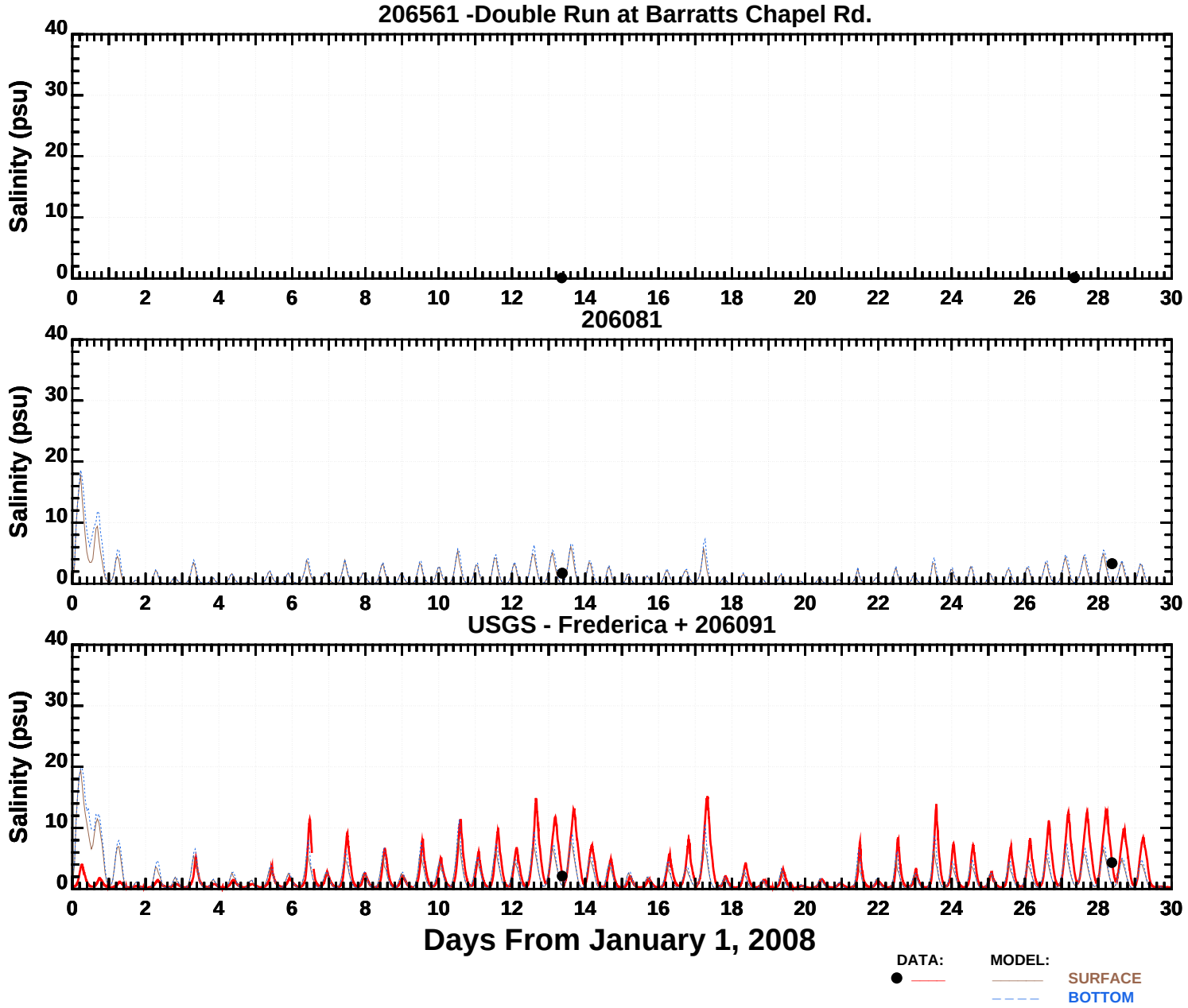

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
330
332
334
336
338
340
342
344
346
348
350
352
354
356
358
360
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

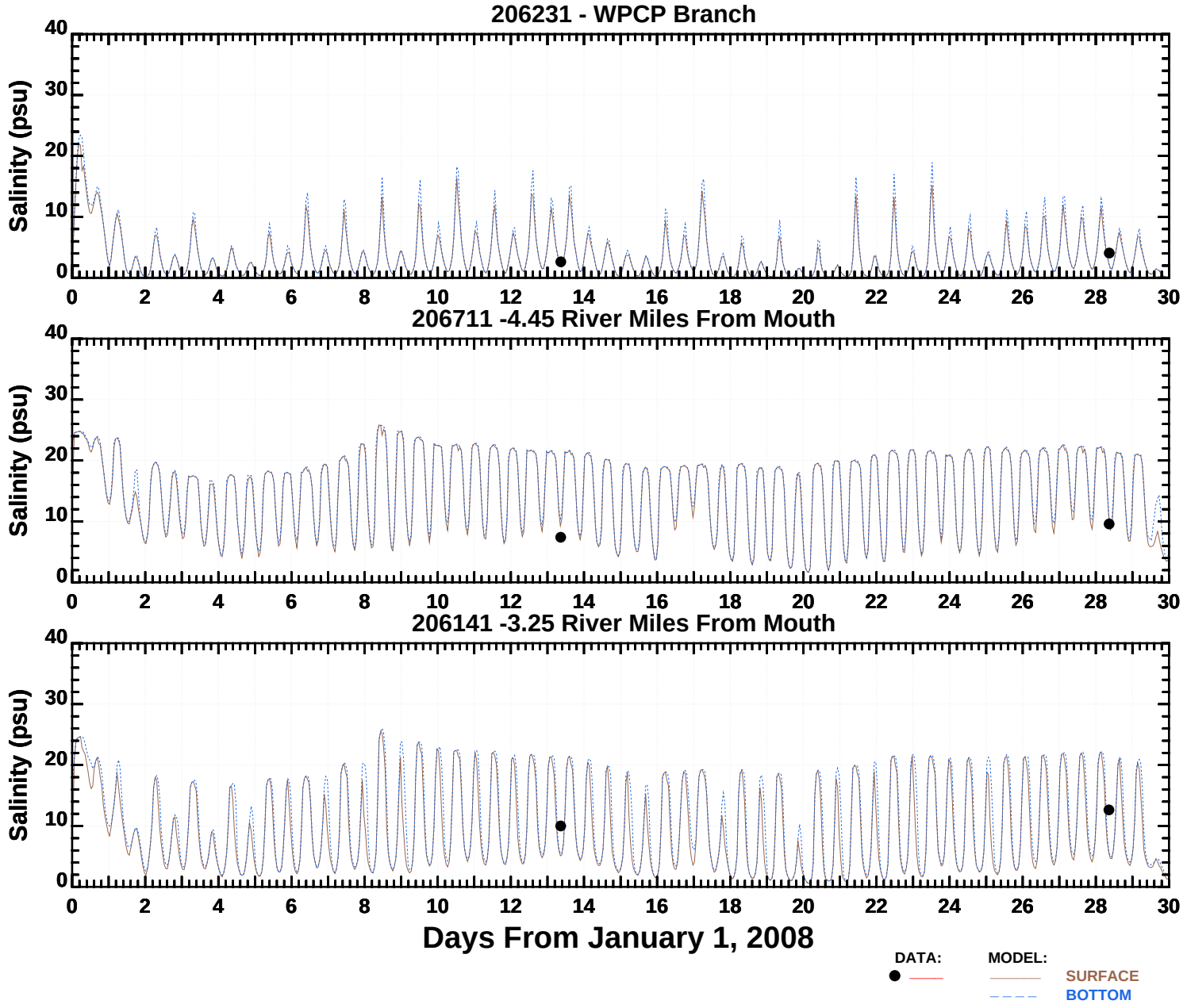
MODEL: ——— SURFACE

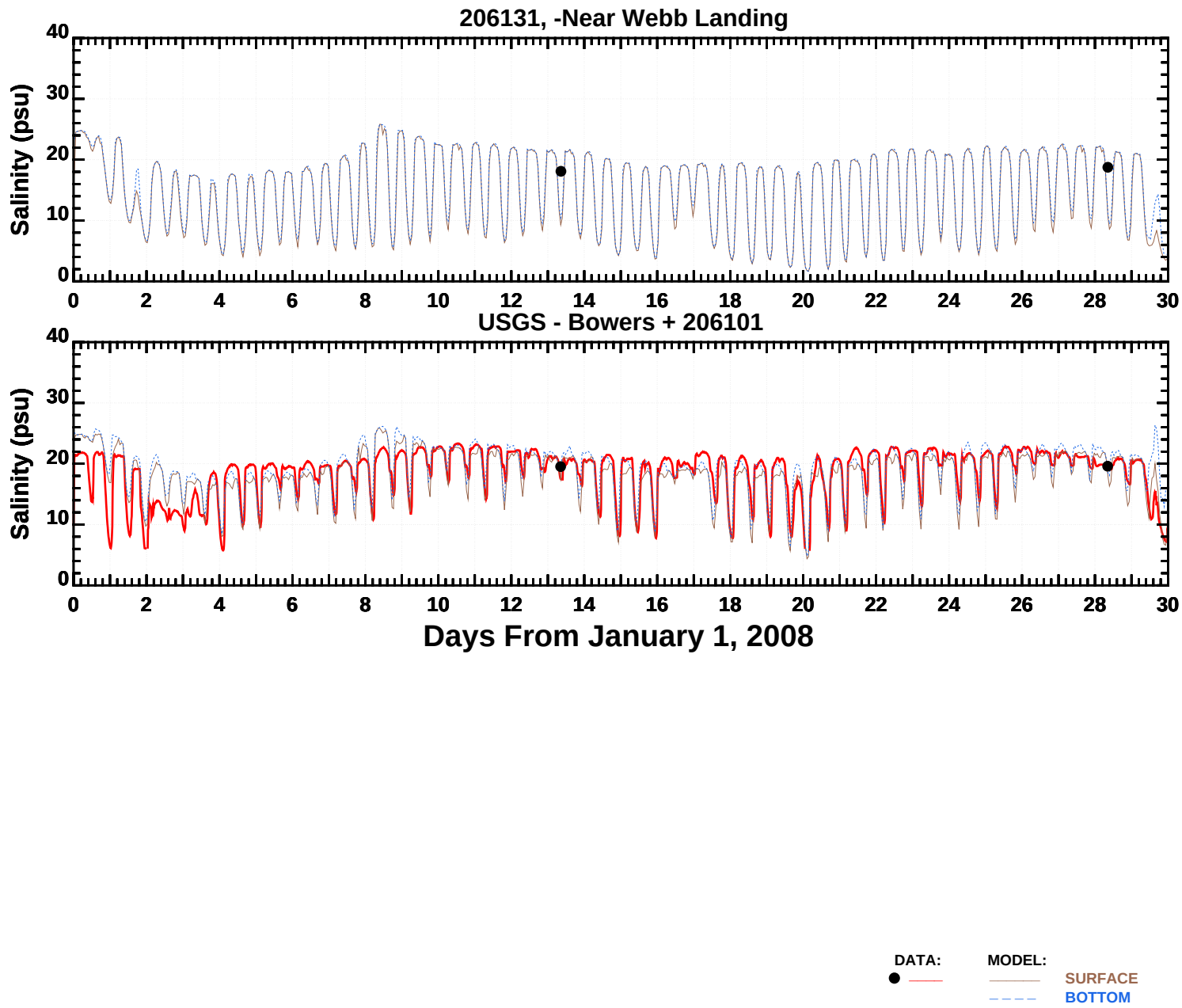
– – – – BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

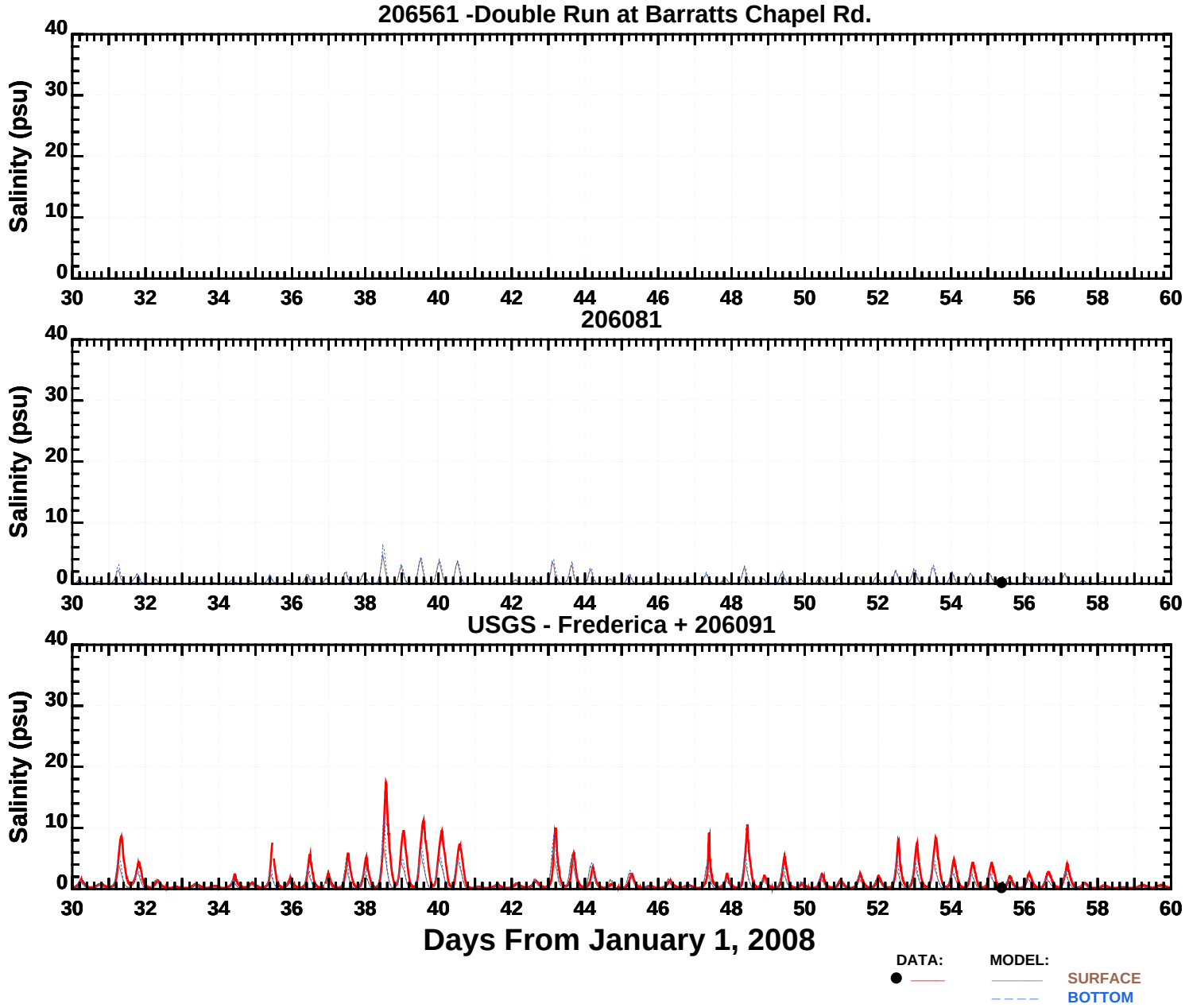
DATE: 1/22/2013 TIME: 13:14: 3


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



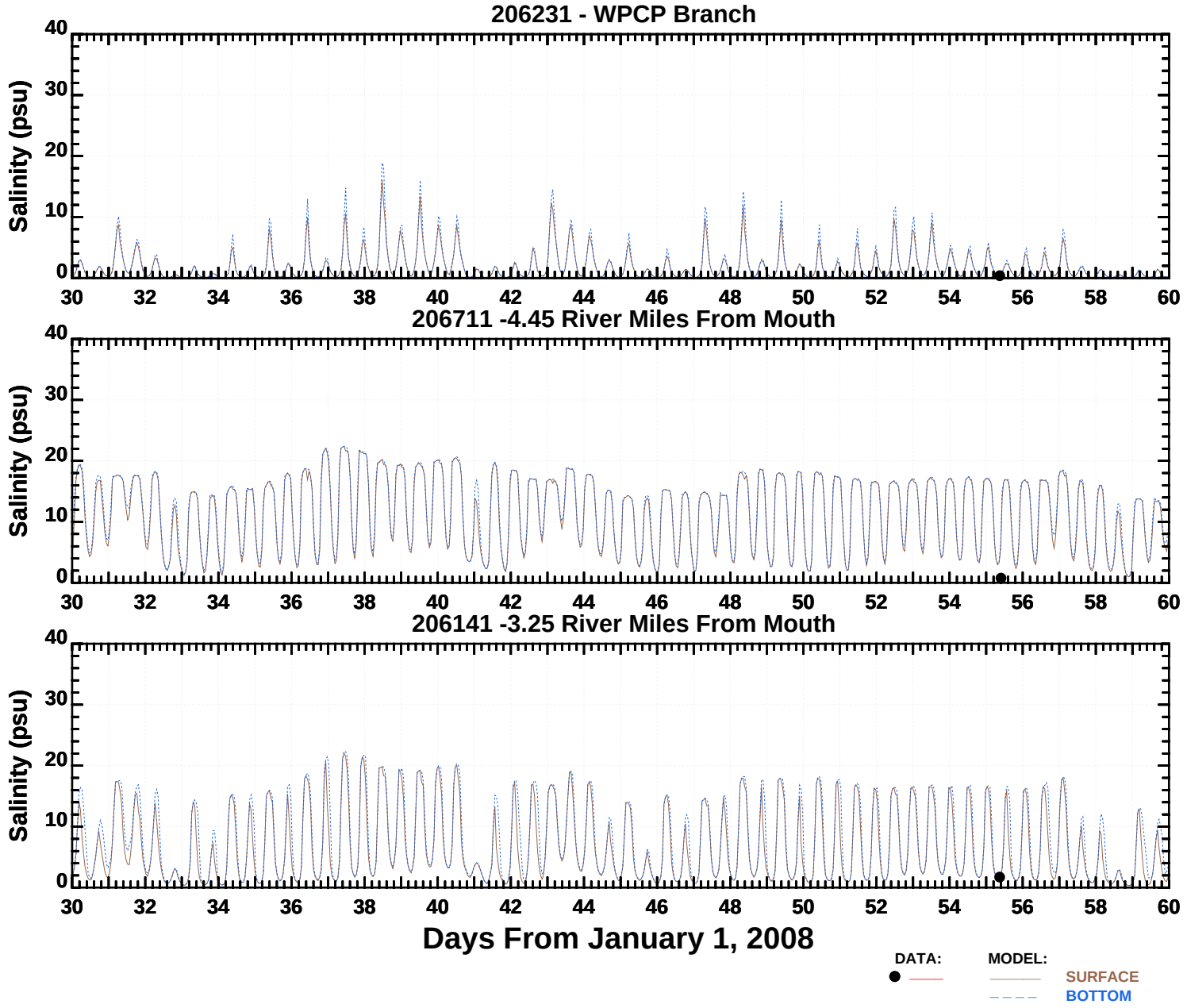
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 3 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

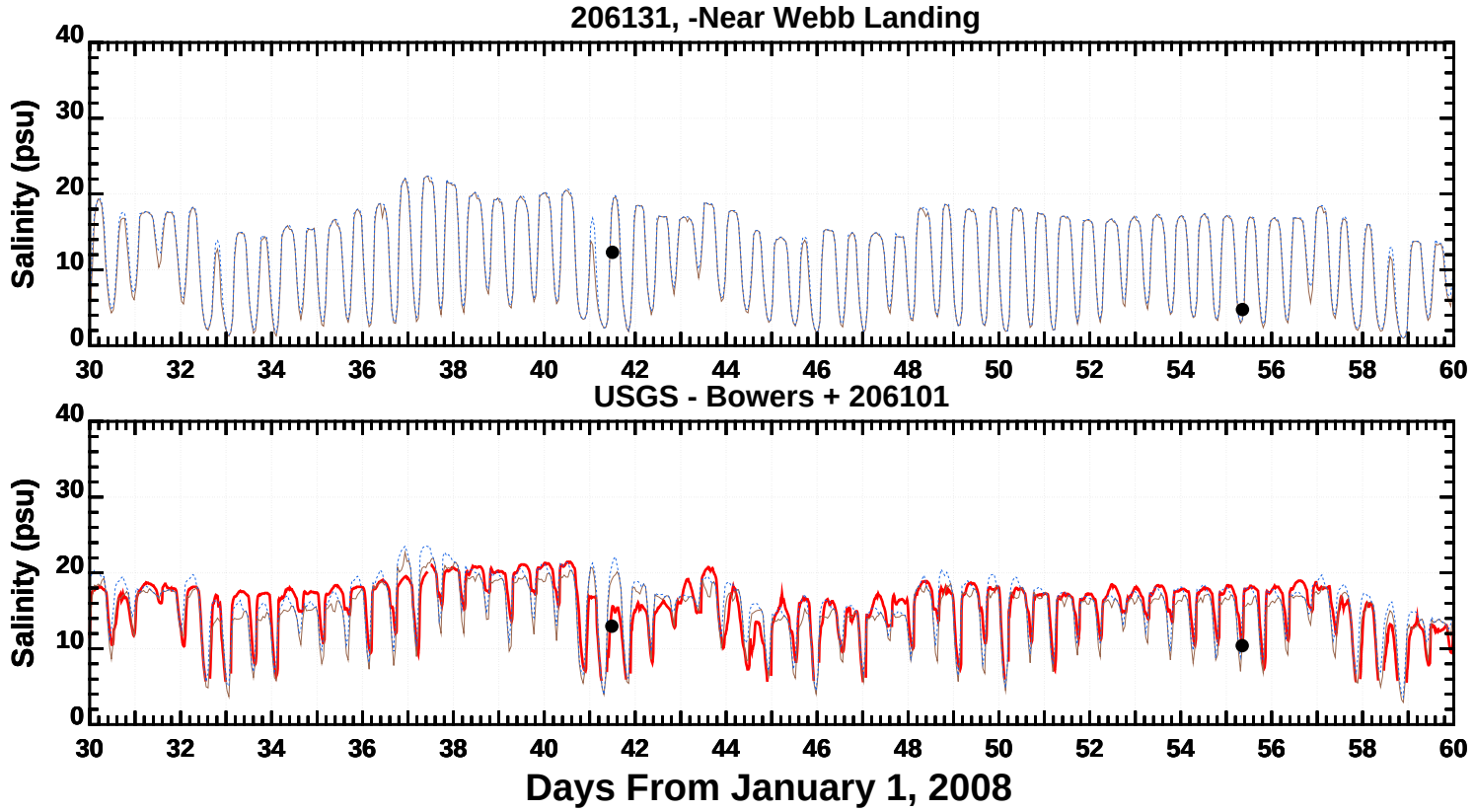
DATE: 1/22/2013 TIME: 13:14: 3



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:14:10

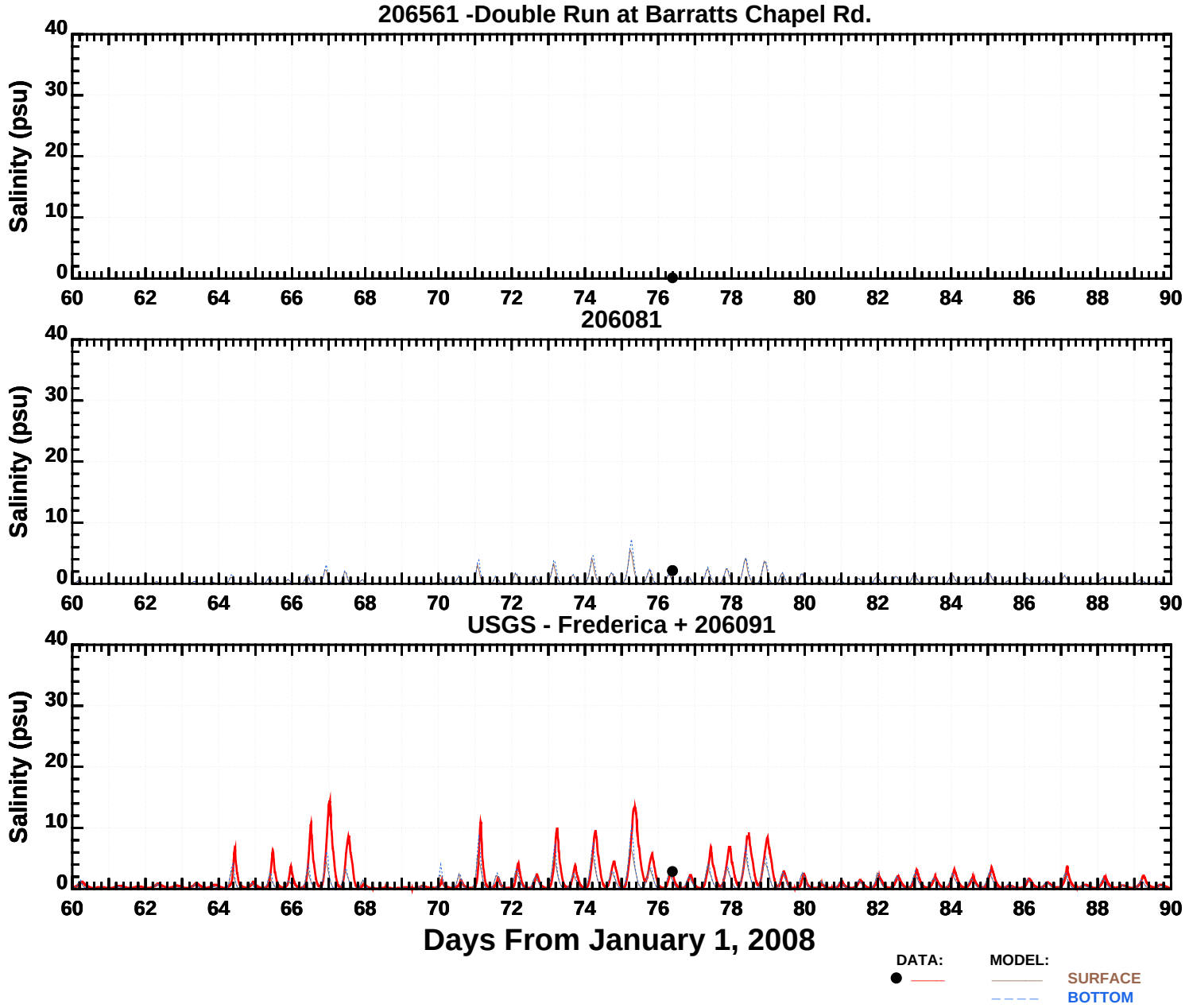

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

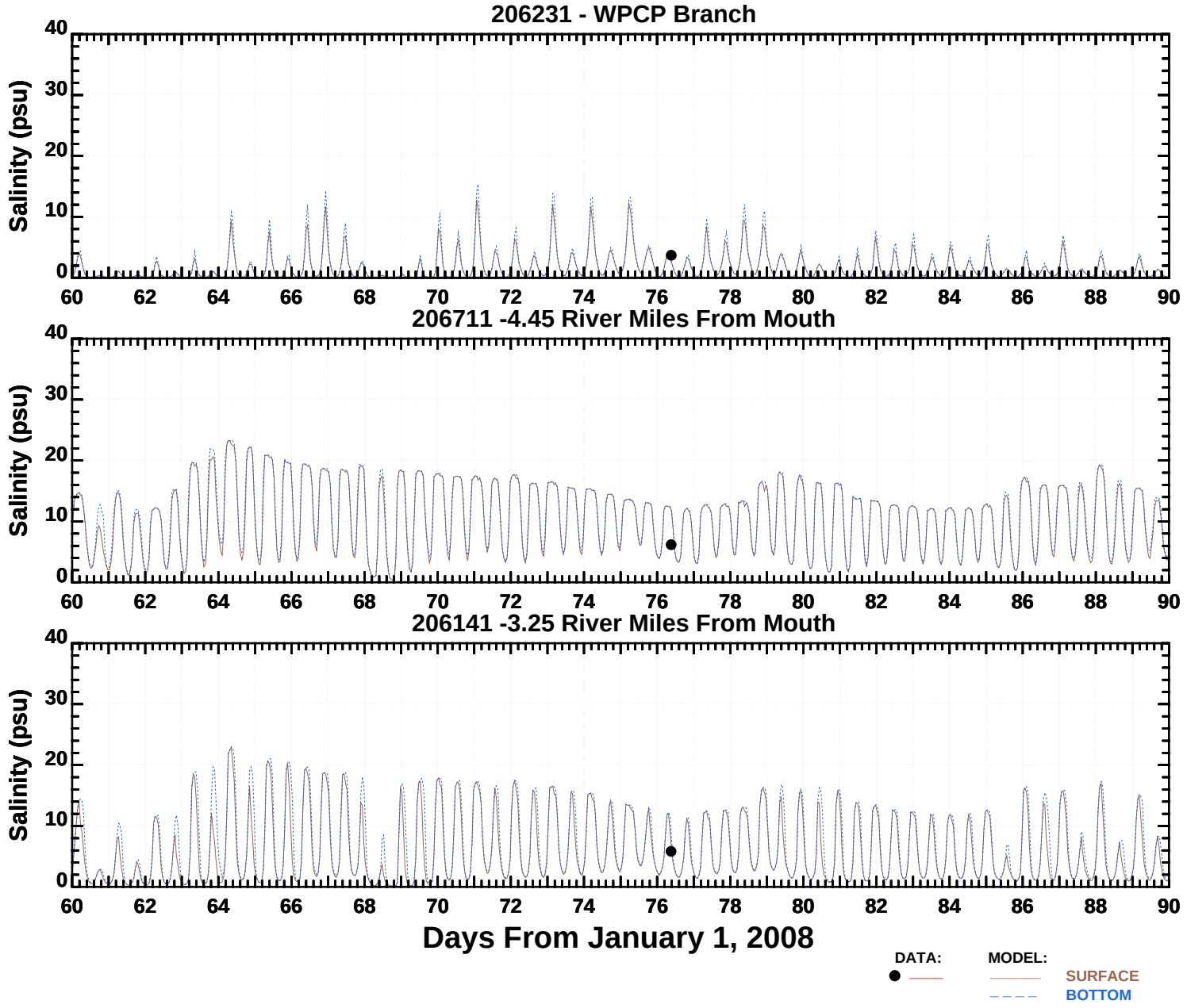
MODEL: ——— SURFACE

– – – – BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

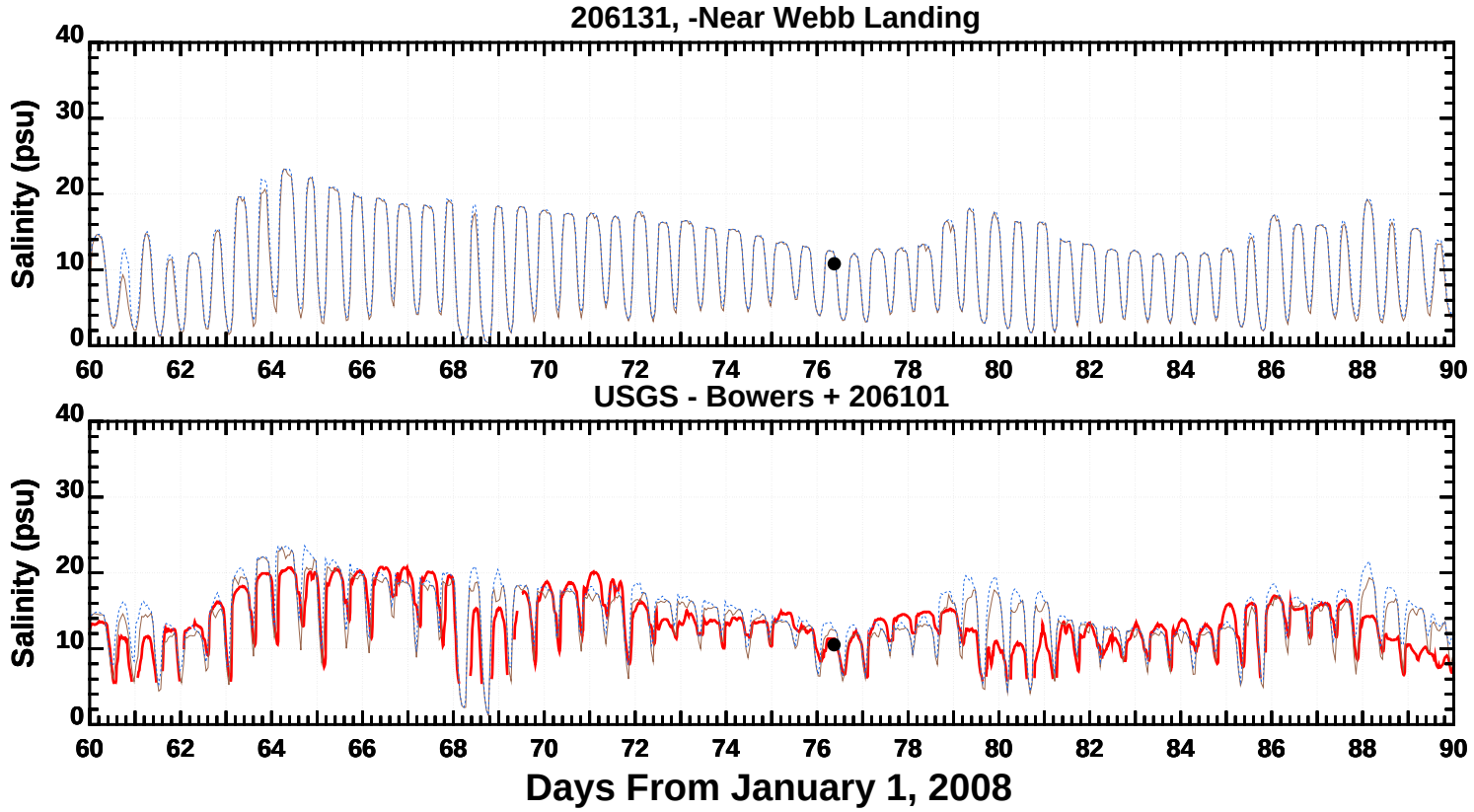
DATE: 1/22/2013 TIME: 13:14:18



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

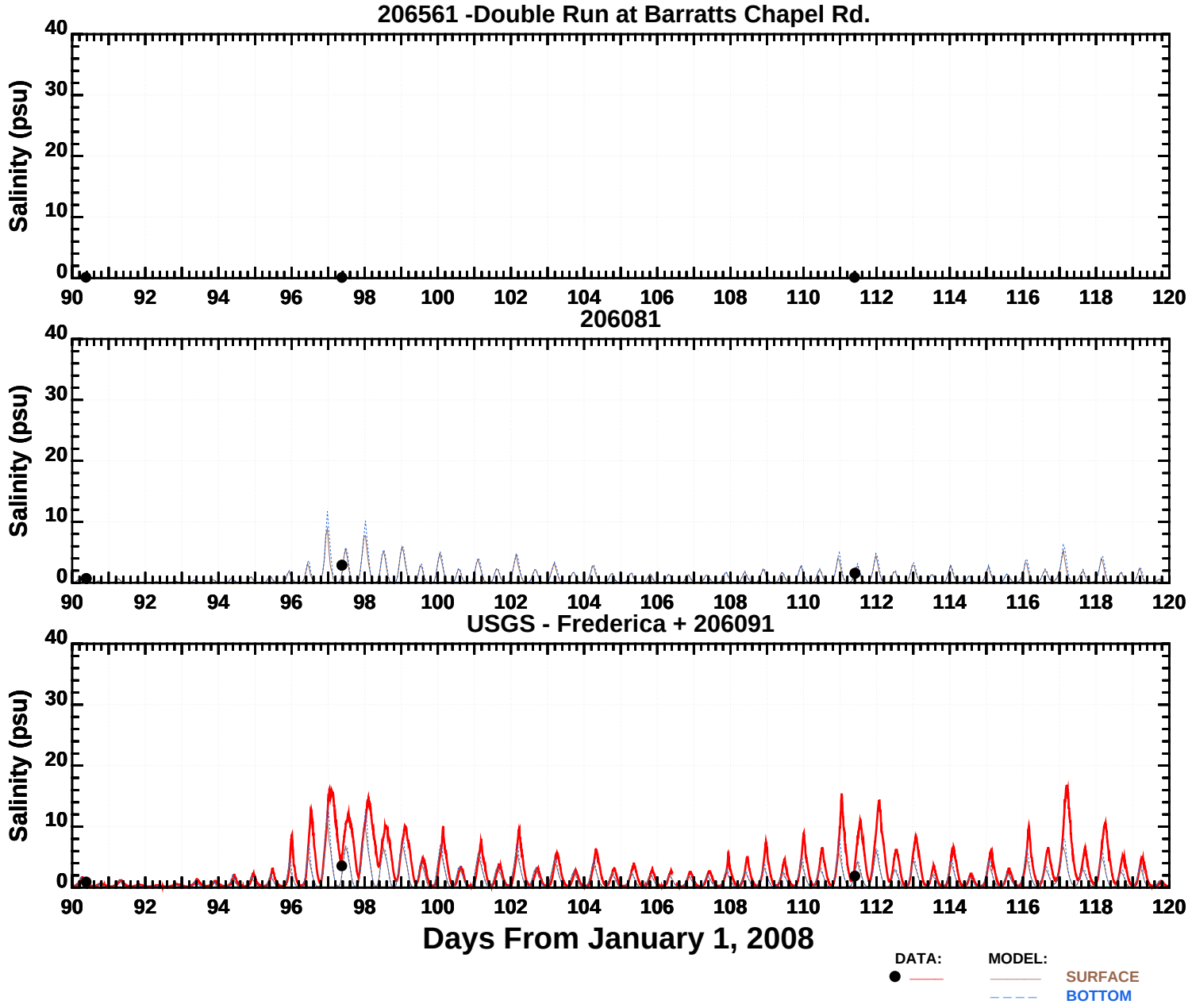
DATE: 1/22/2013 TIME: 13:14:18



DATA: ● ——

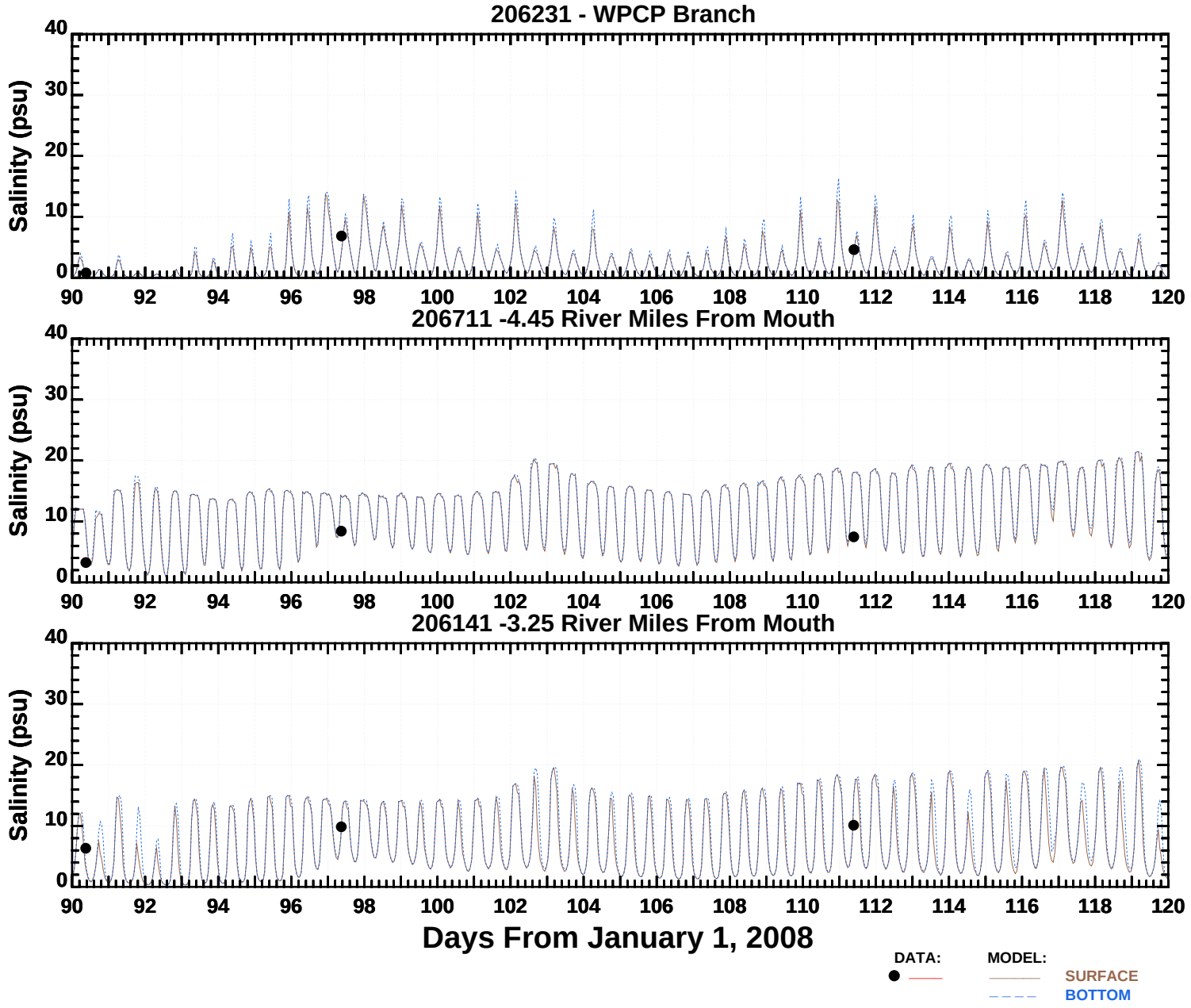
MODEL: ——— SURFACE

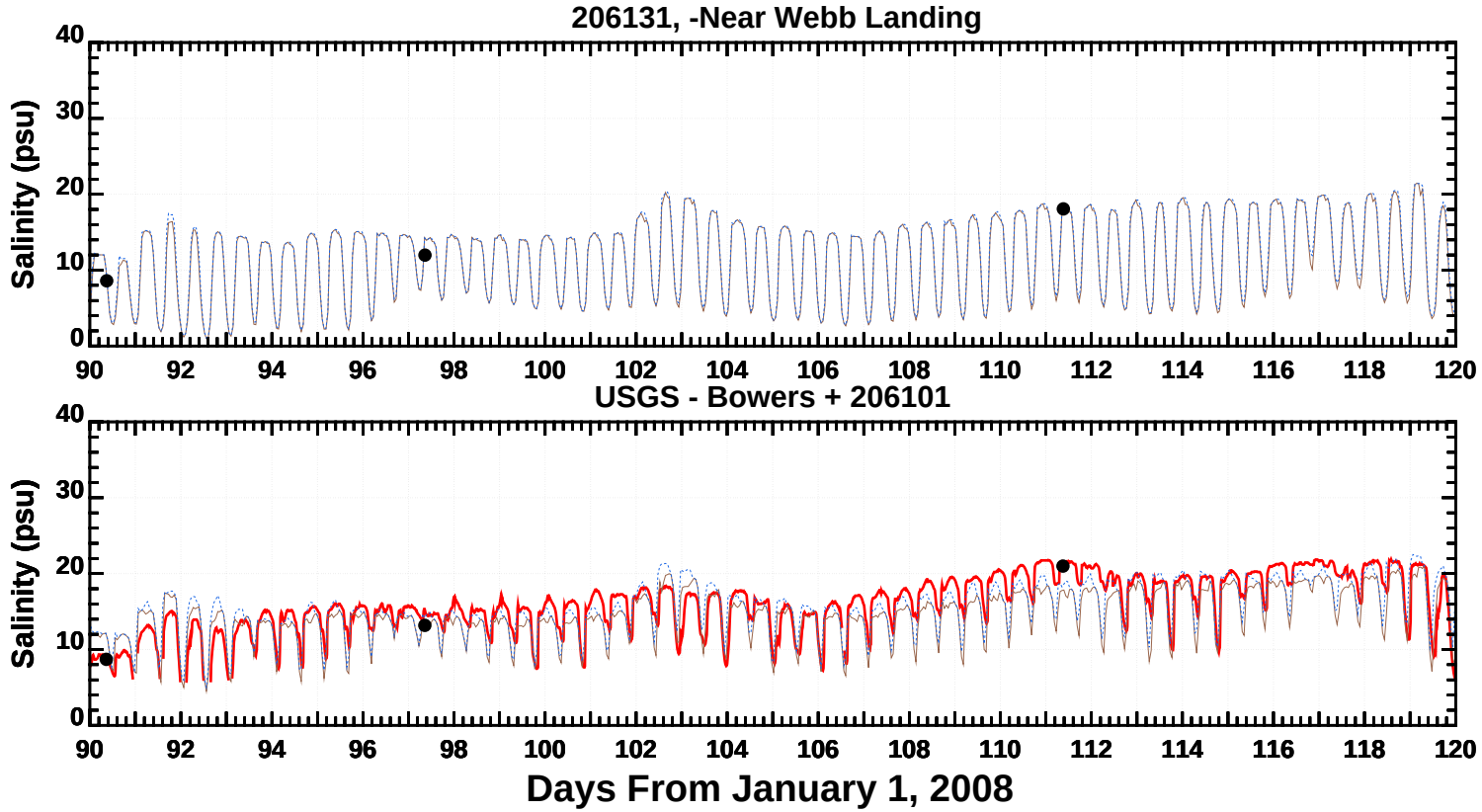
– – – – BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:14:26

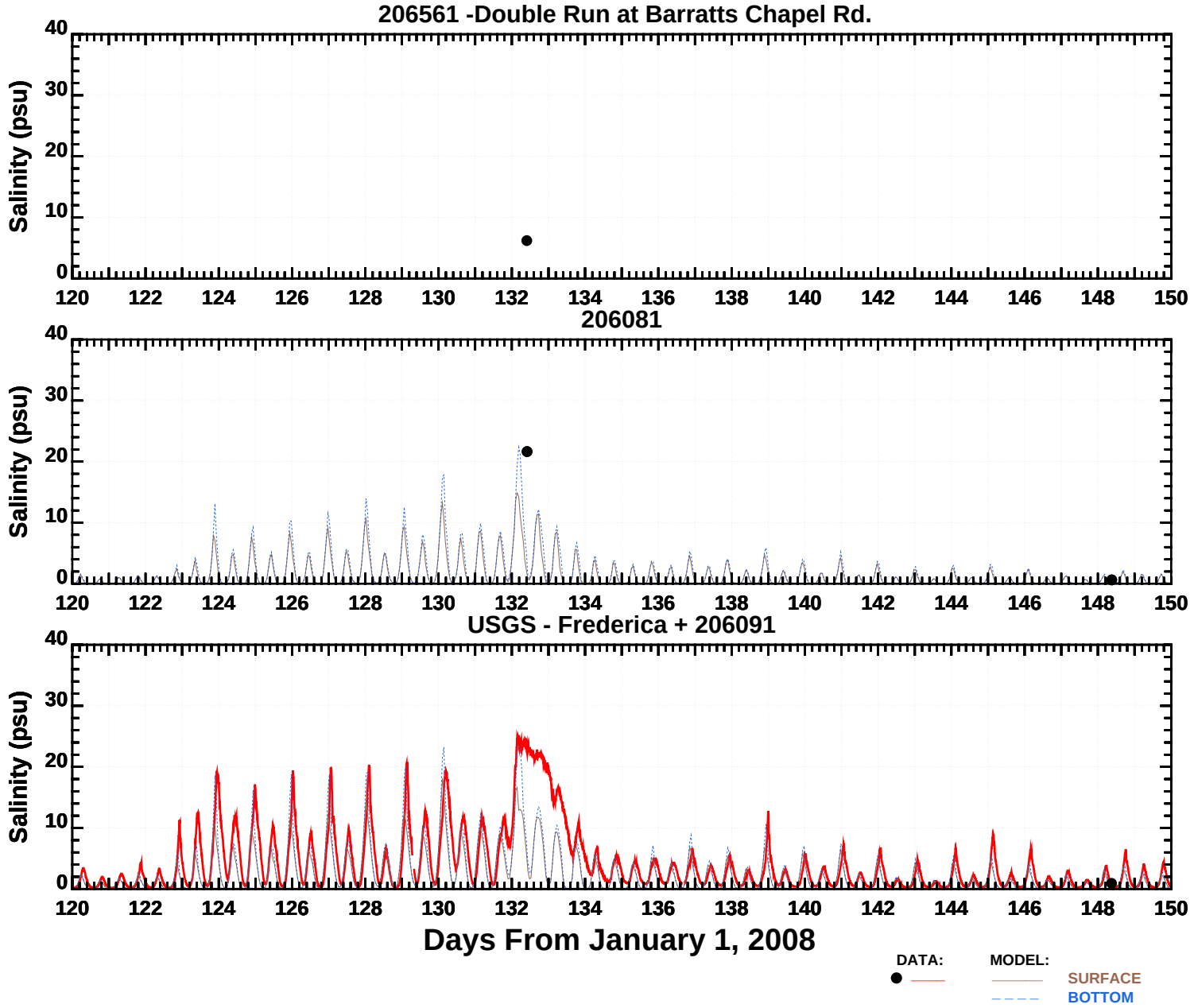

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
90
92
94
96
98
100
102
104
106
108
110
112
114
116
118
120
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

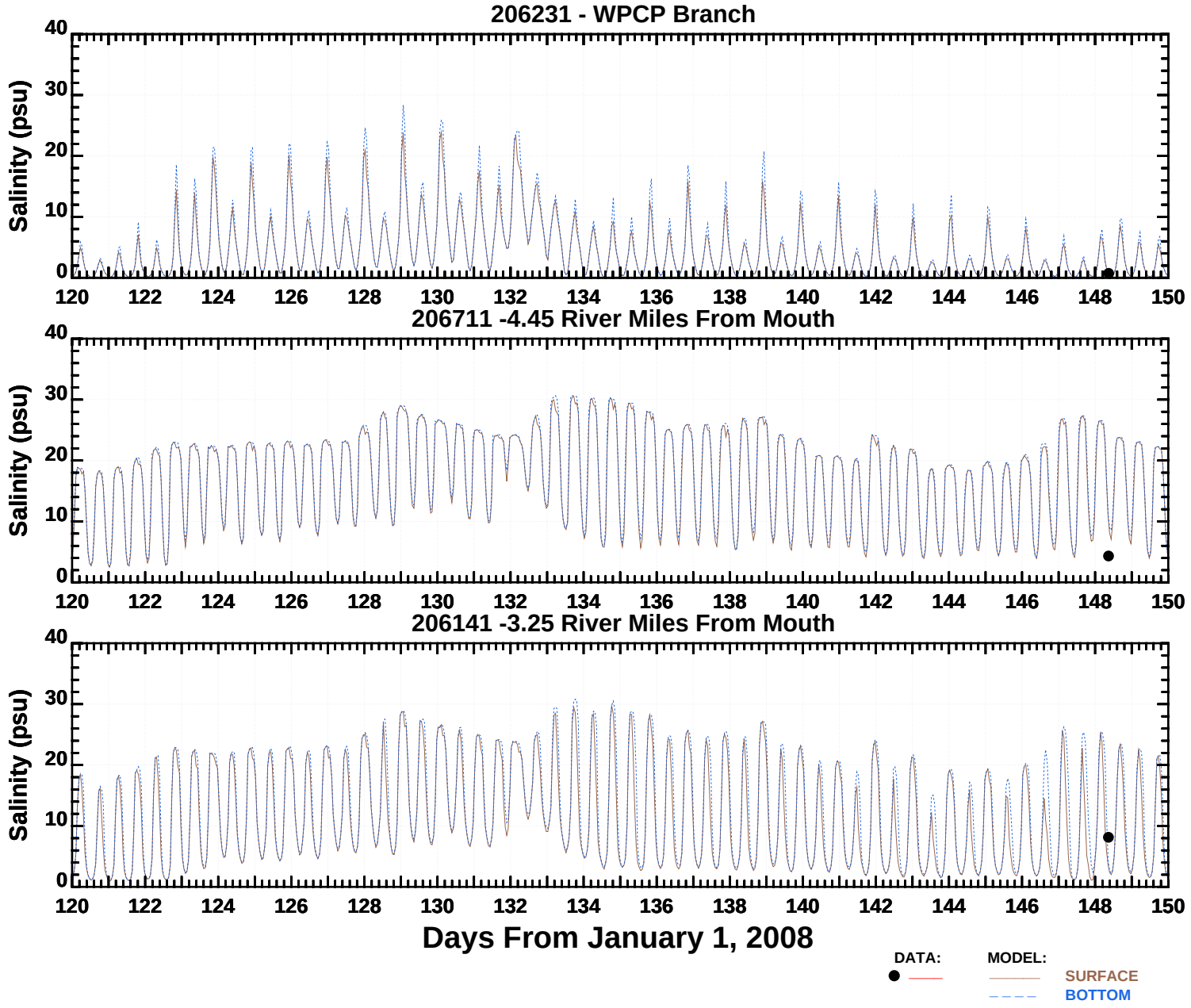
MODEL: ——— SURFACE

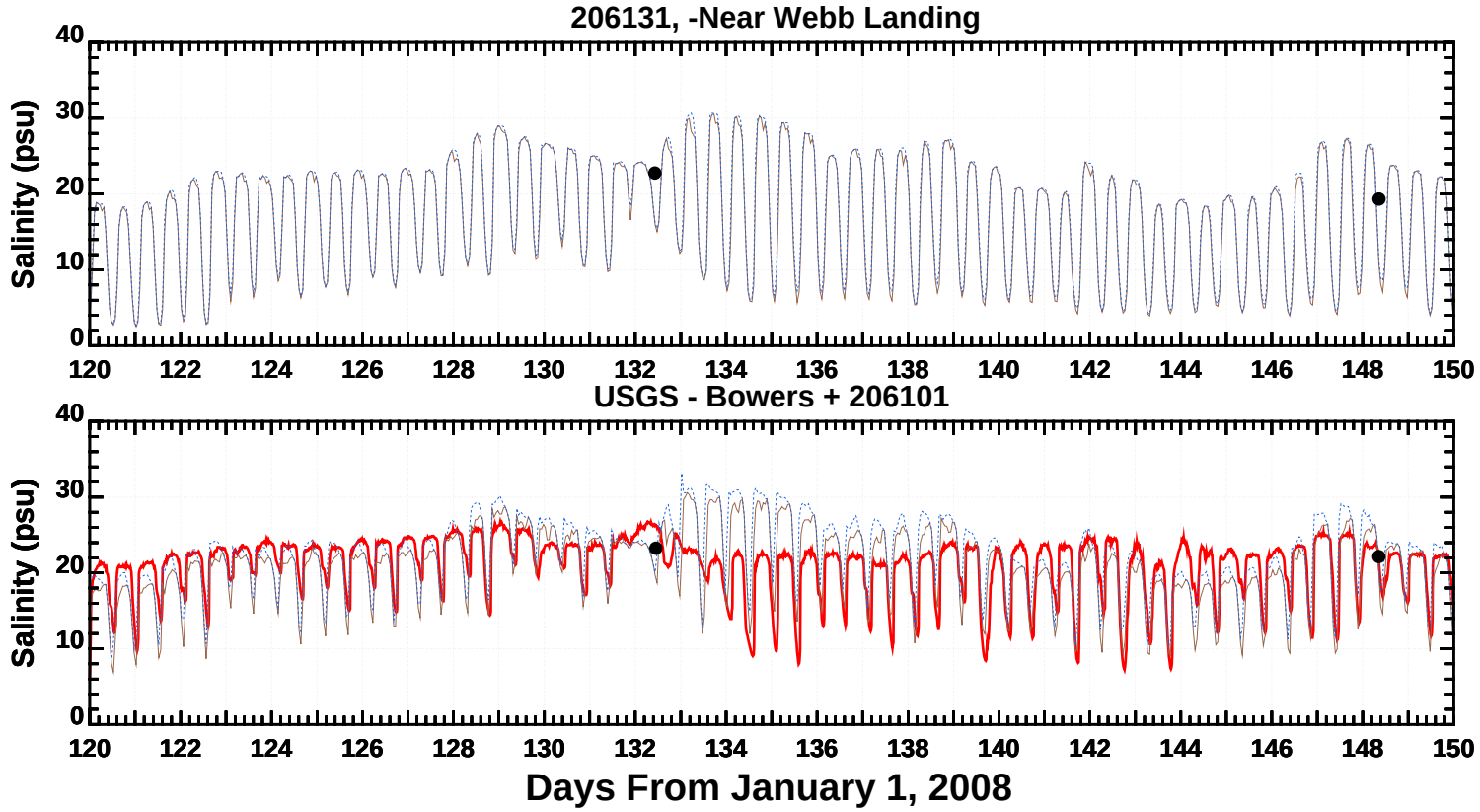
– – – – BOTTOM



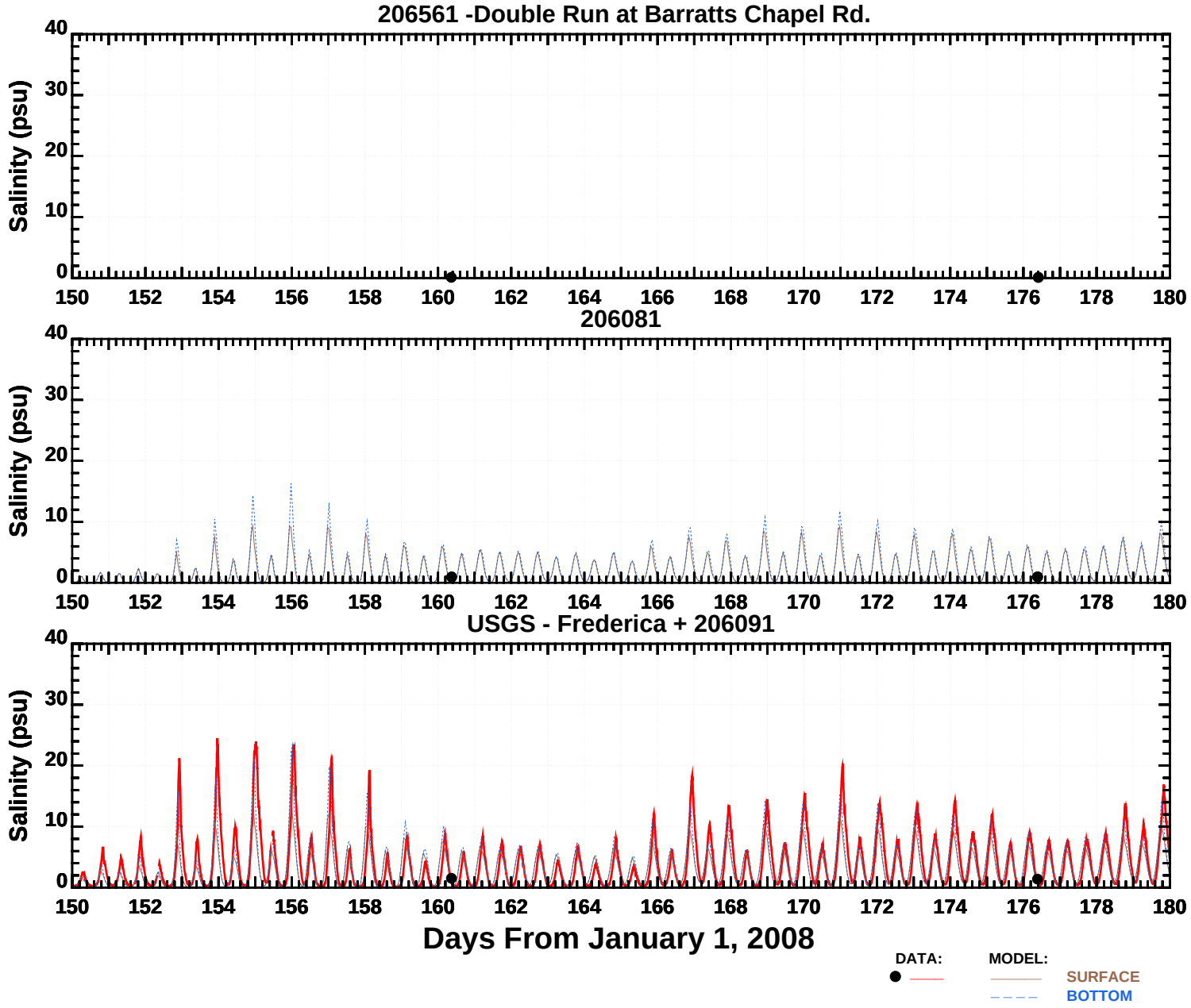
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:14:33


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

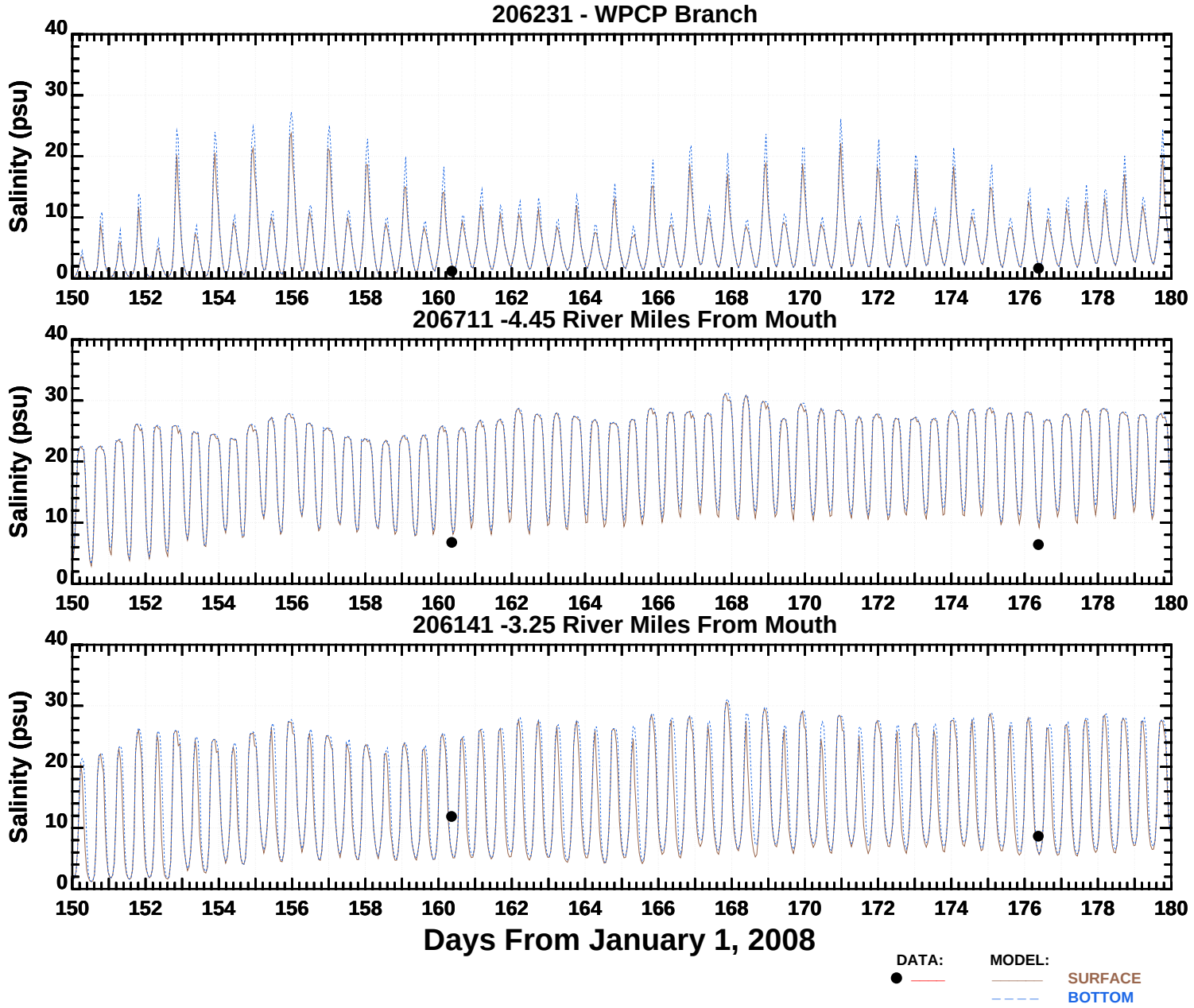


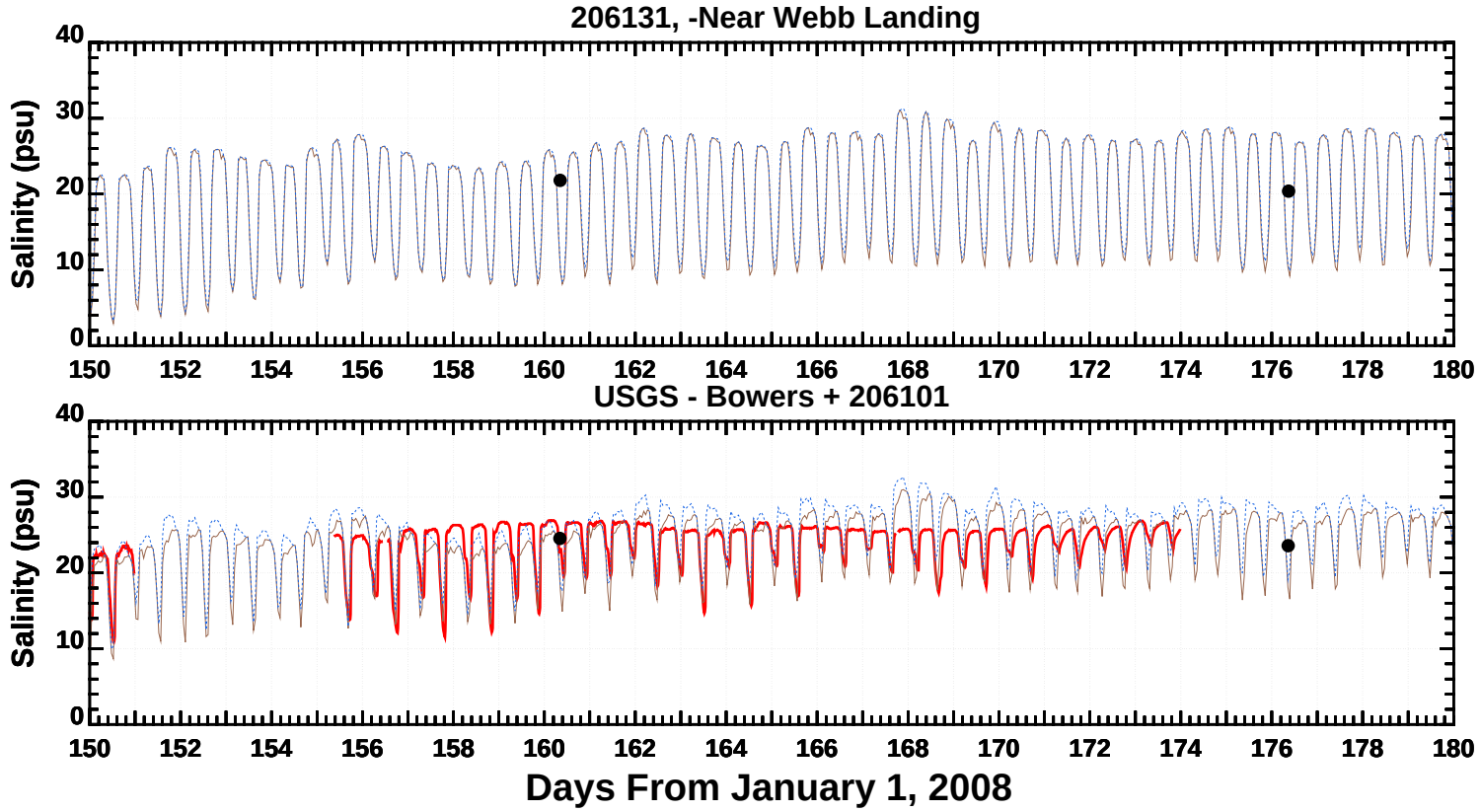
DATA: ● MODEL: SURFACE BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

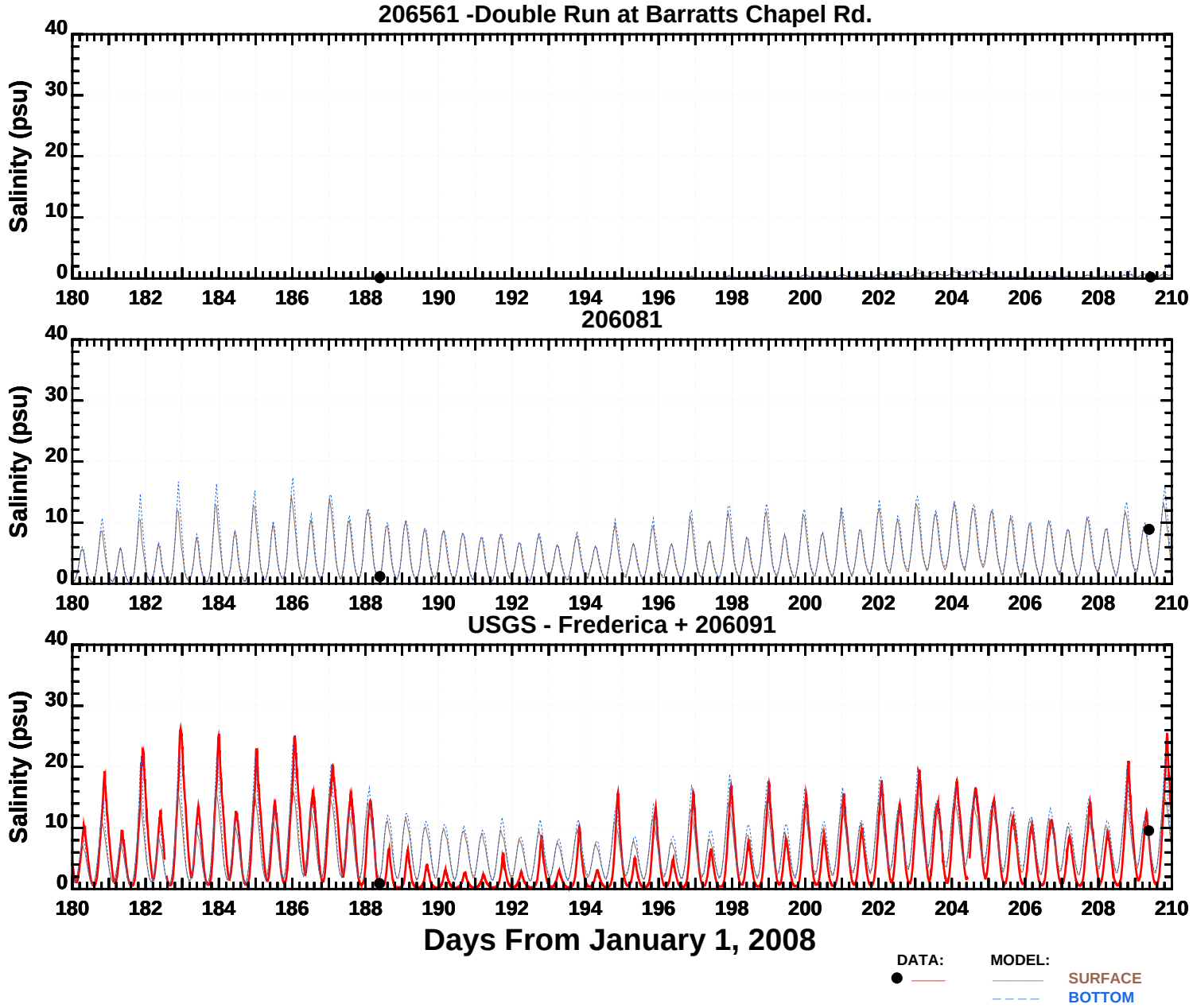
DATE: 1/22/2013 TIME: 13:14:41


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: MODEL: SURFACE BOTTOM

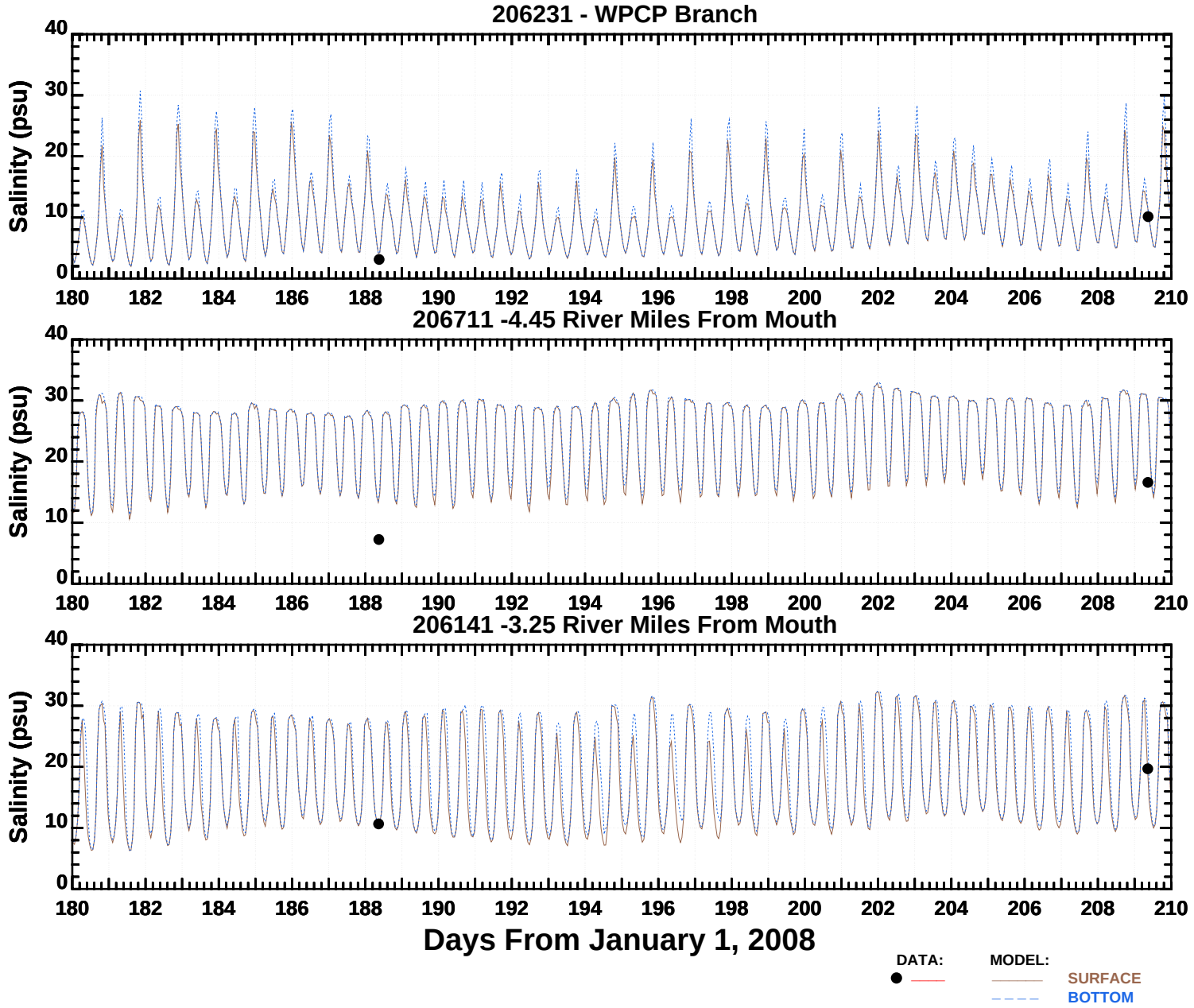
DATE: 1/22/2013 TIME: 13:14:41

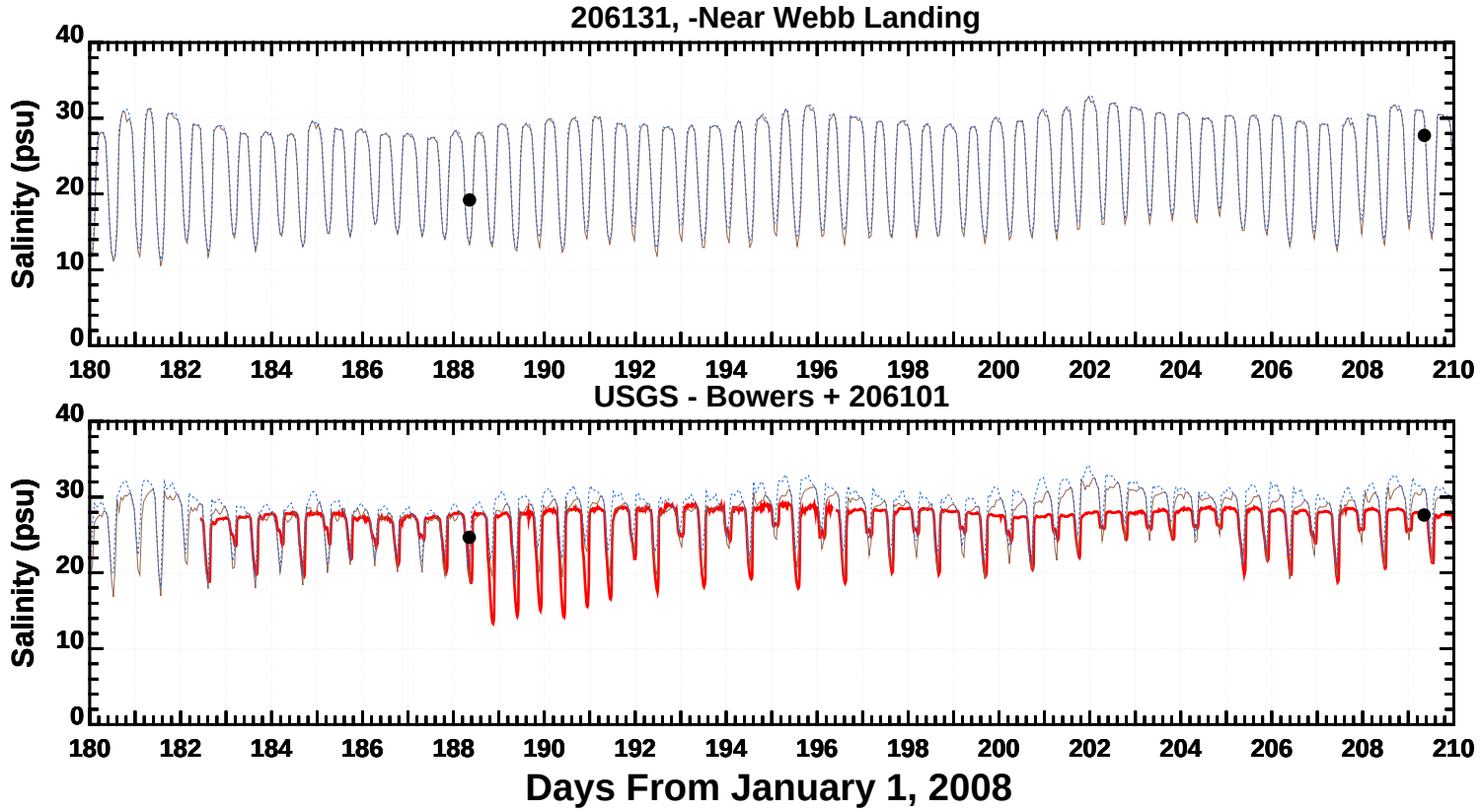


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:14:49

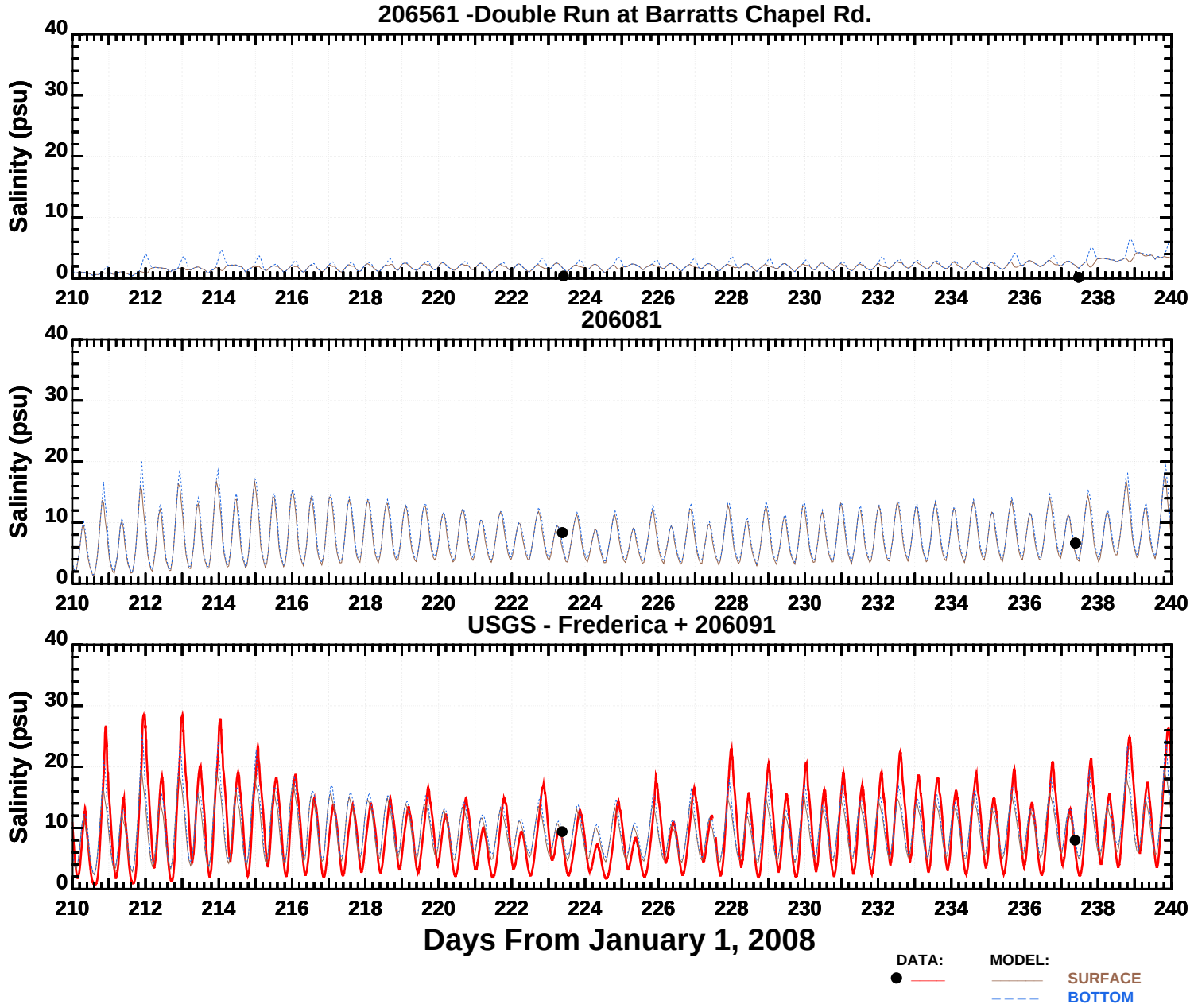

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

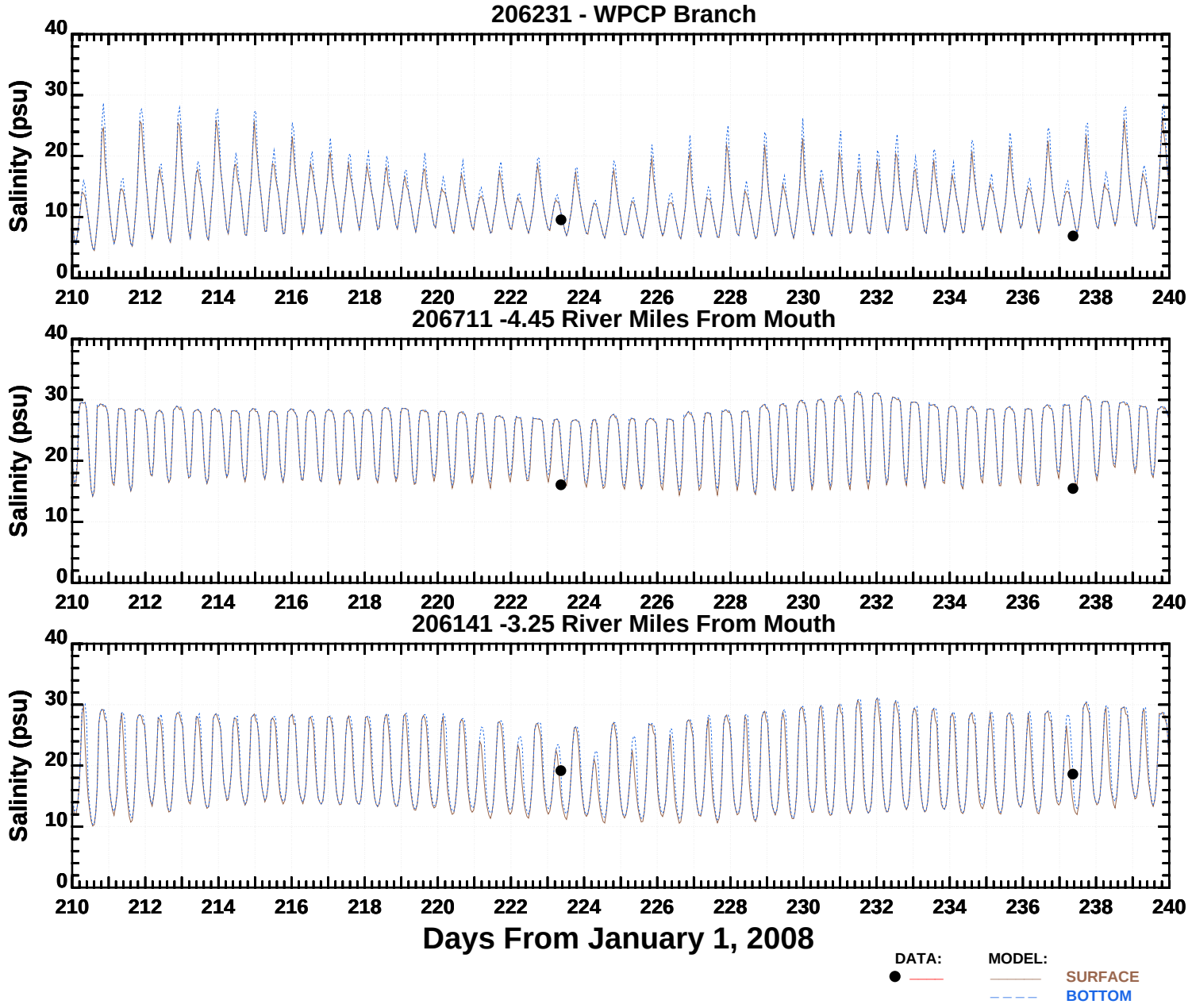


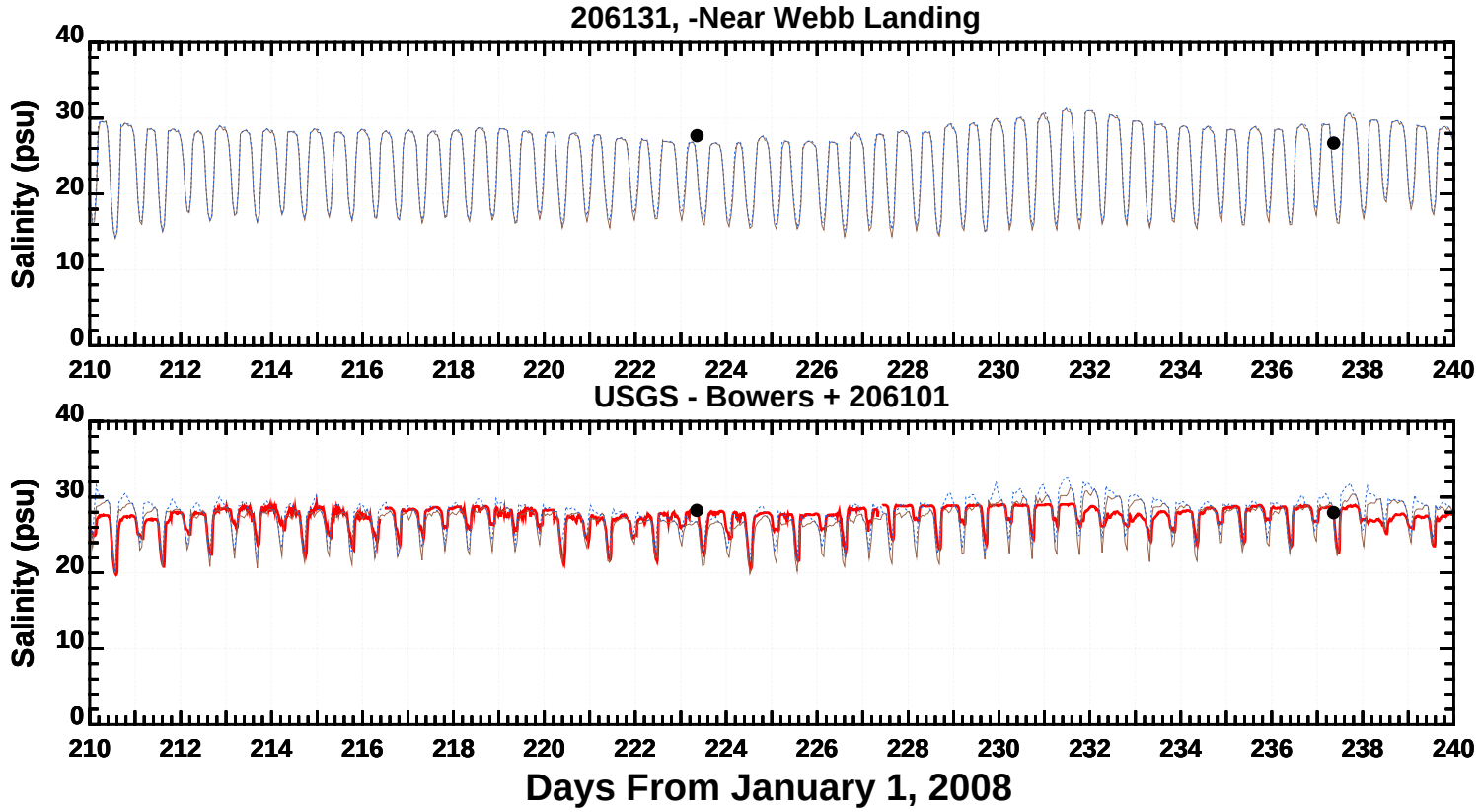
DATA: ● MODEL: SURFACE BOTTOM

DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 3 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:14:49


206561 -Double Run at Barratts Chapel Rd.
Salinity (psu)
0
10
20
30
40
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
206081
Salinity (psu)
USGS - Frederica + 206091
Salinity (psu)
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

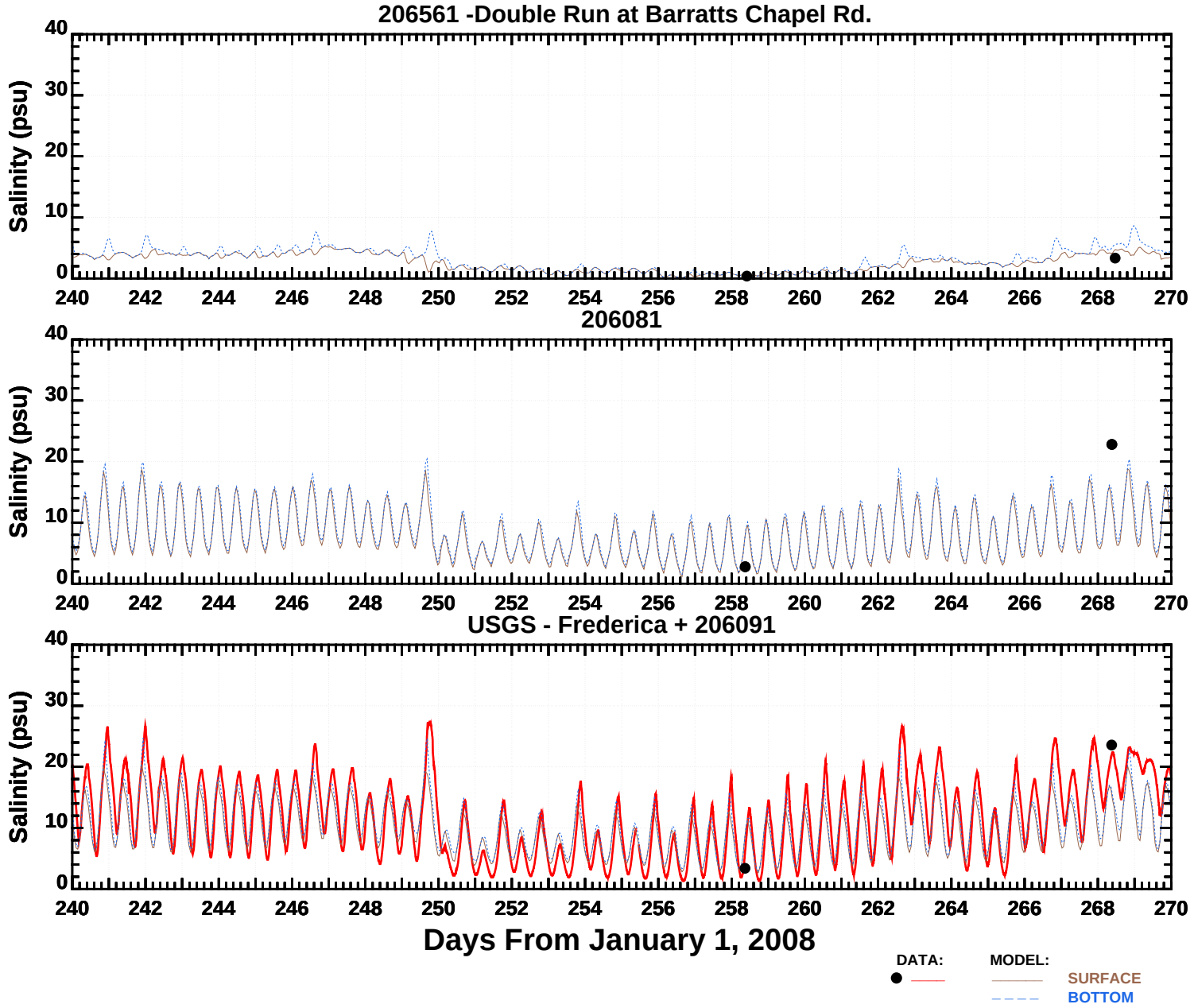

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

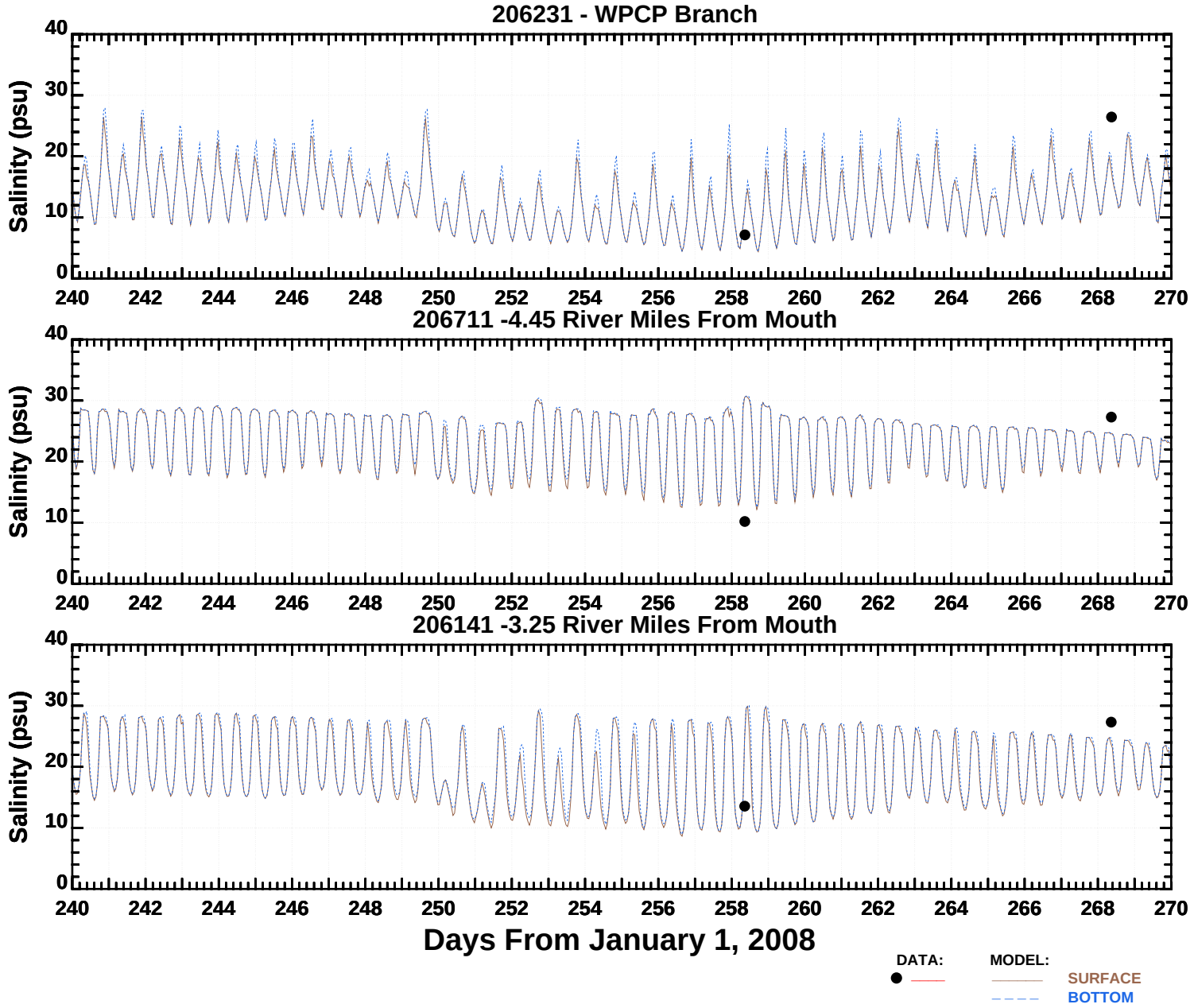
MODEL: ——— SURFACE

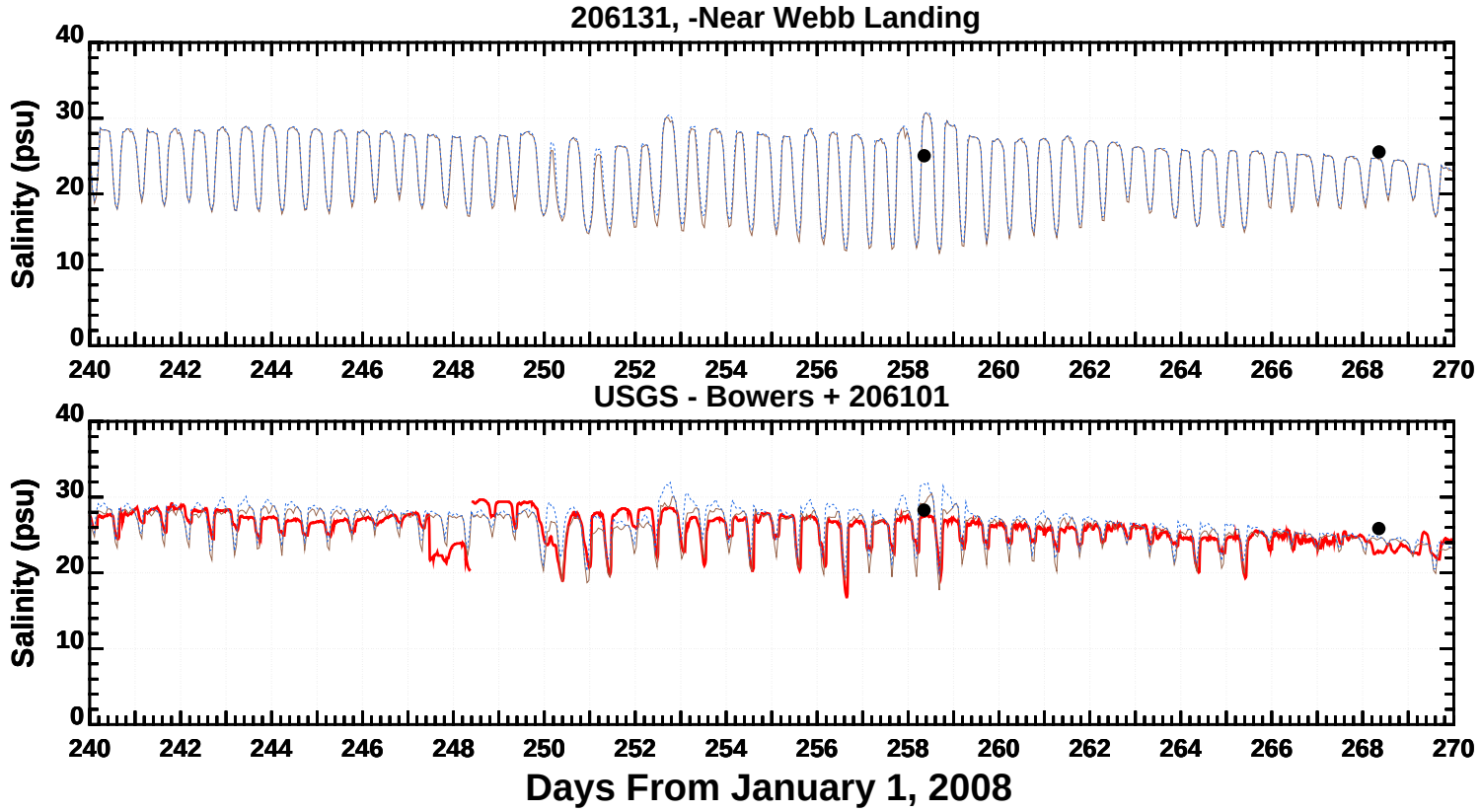
– – – – BOTTOM



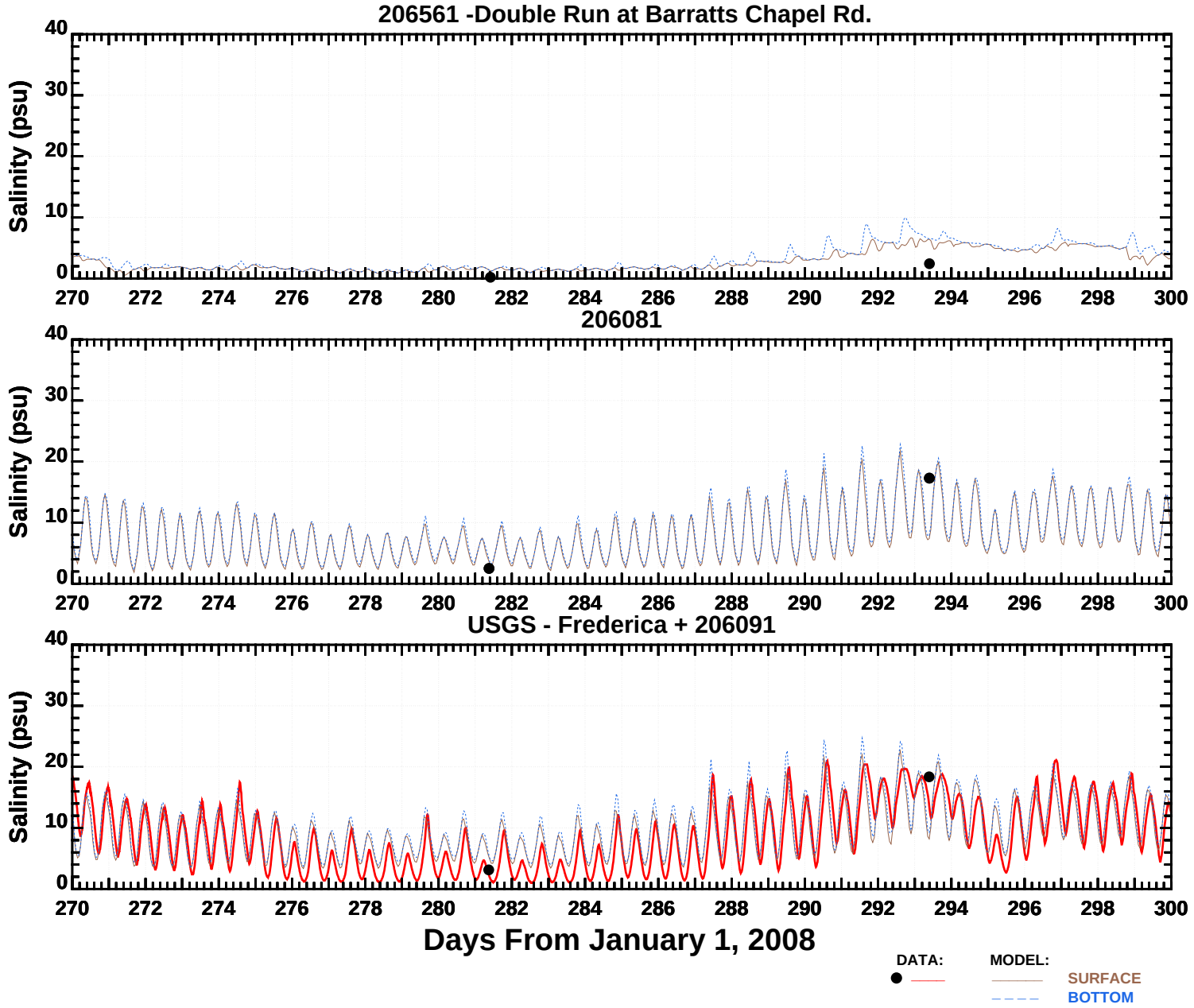
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:15: 4


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
240
242
244
246
248
250
252
254
256
258
260
262
264
266
268
270
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

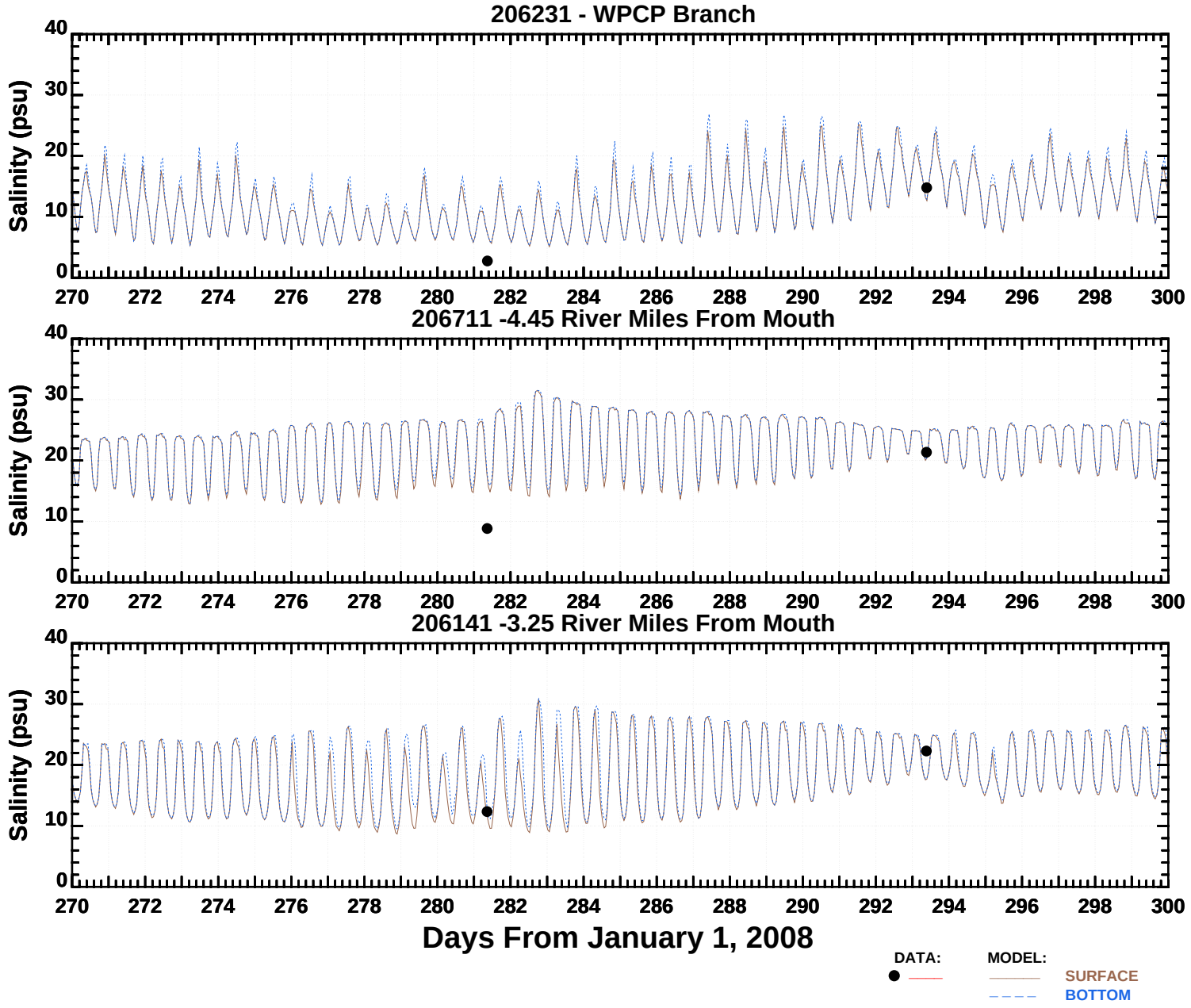


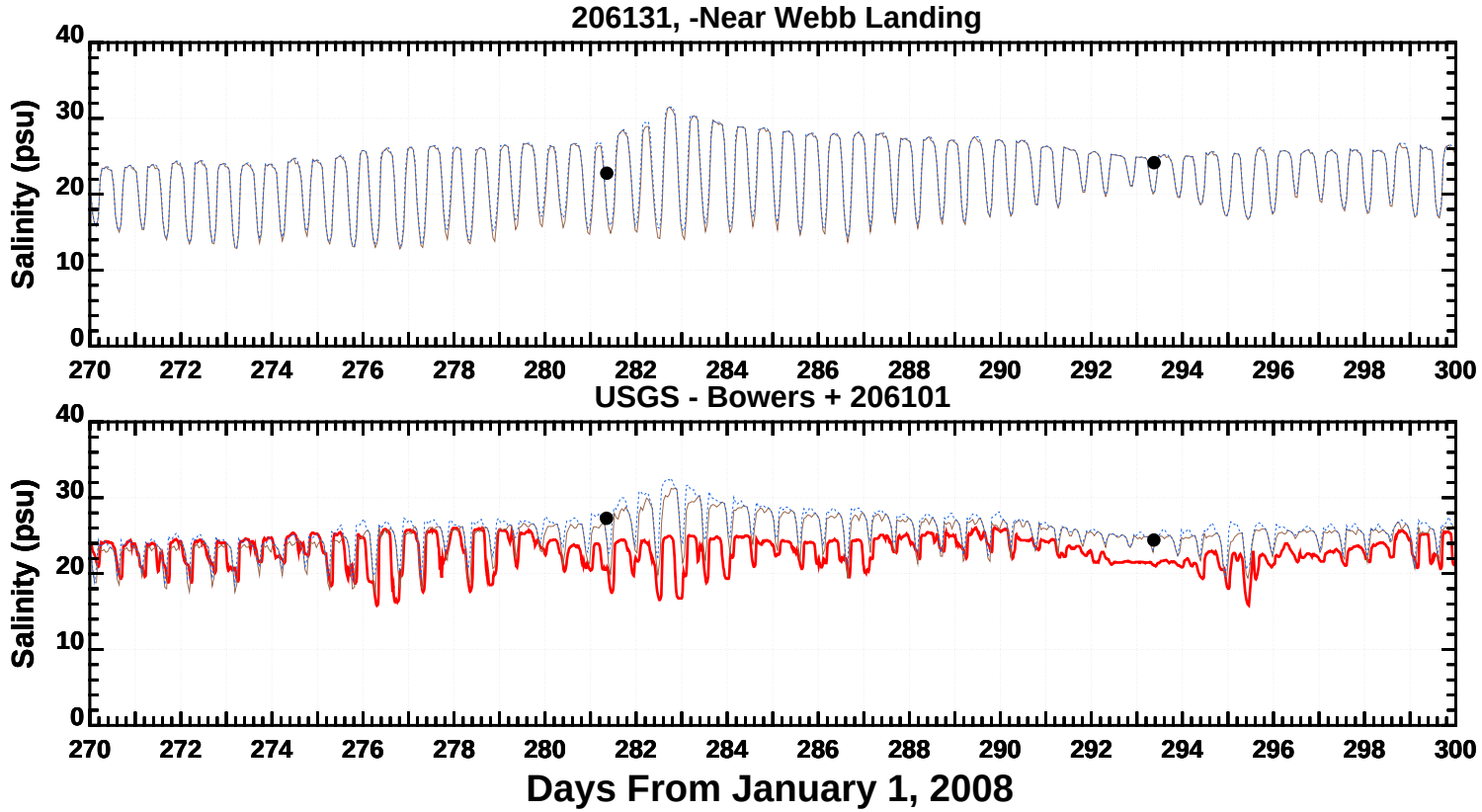
DATA: MODEL: SURFACE BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:15:12

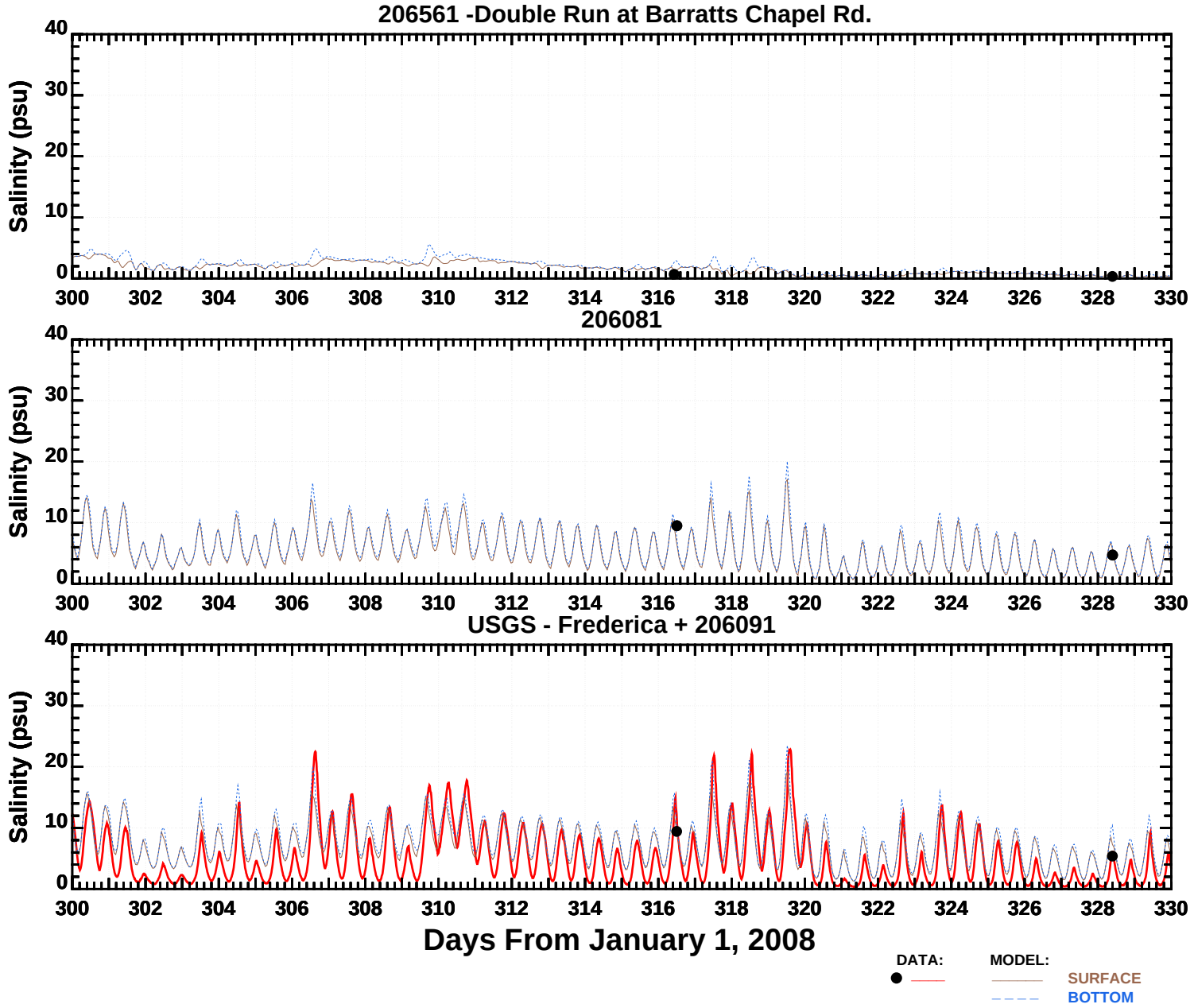

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
270
272
274
276
278
280
282
284
286
288
290
292
294
296
298
300
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

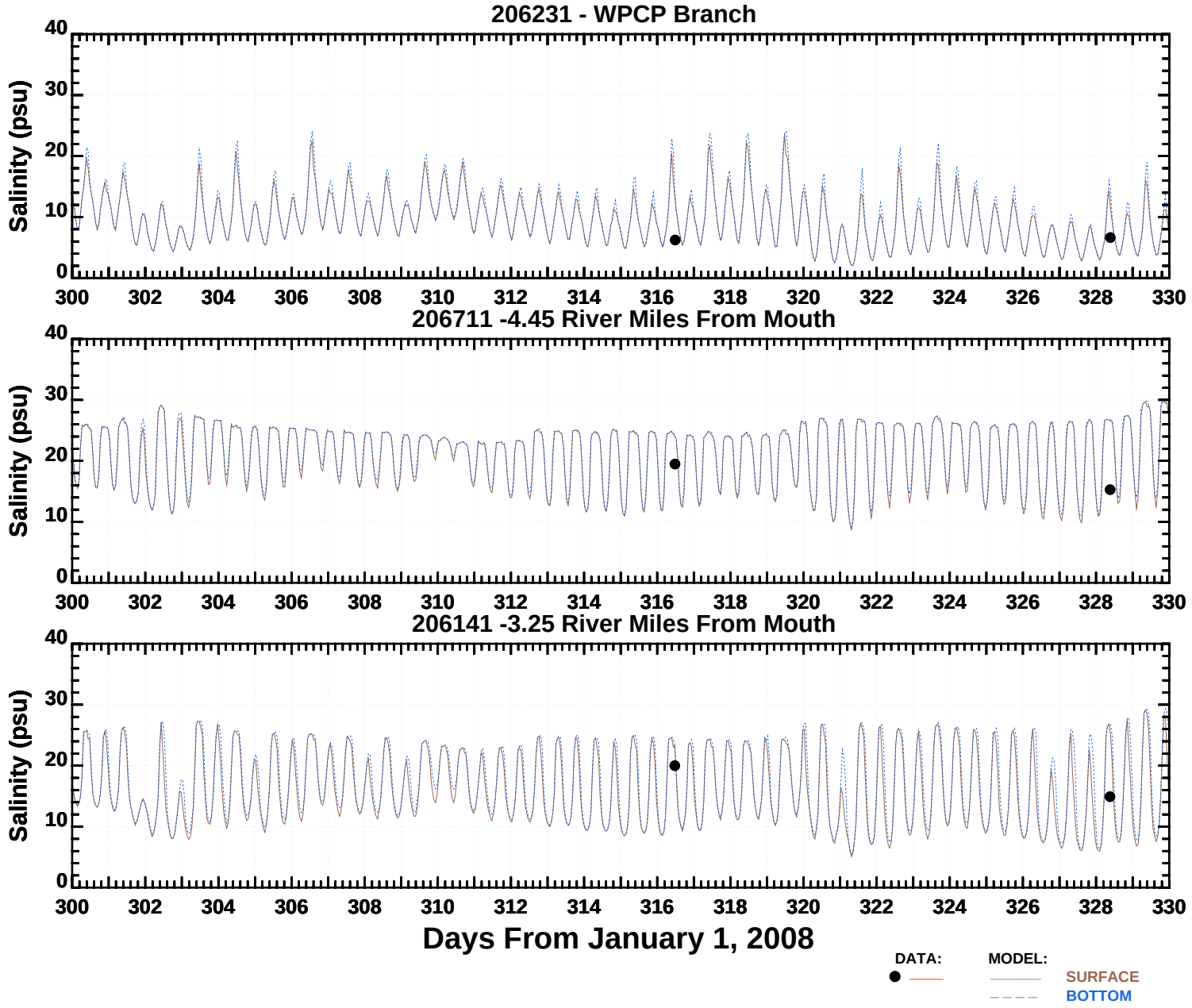


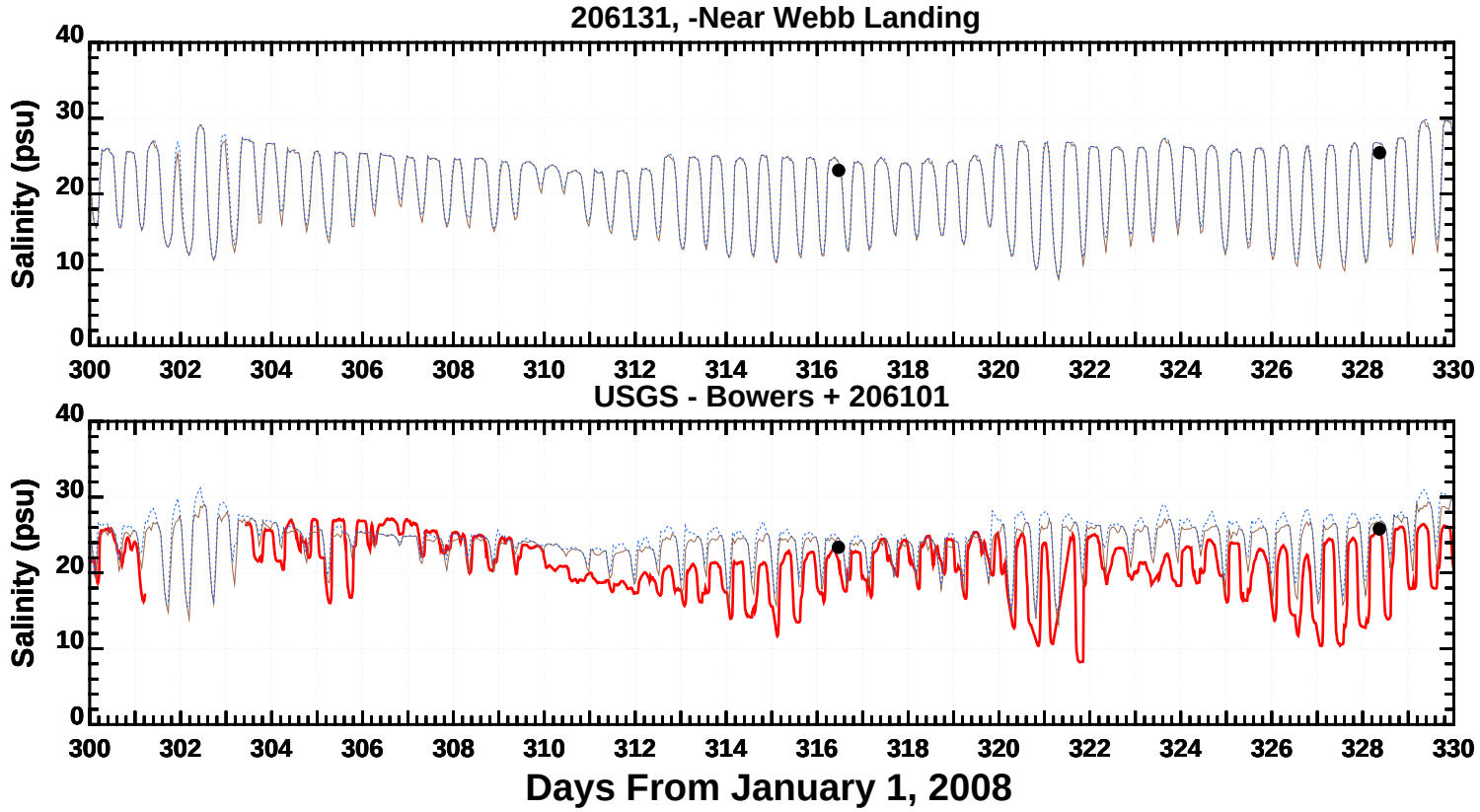
DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM


206561 -Double Run at Barratts Chapel Rd.
Salinity (psu)
0
10
20
30
40
300
302
304
306
308
310
312
314
316
318
320
322
324
326
328
330
206081
USGS - Frederica + 206091
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

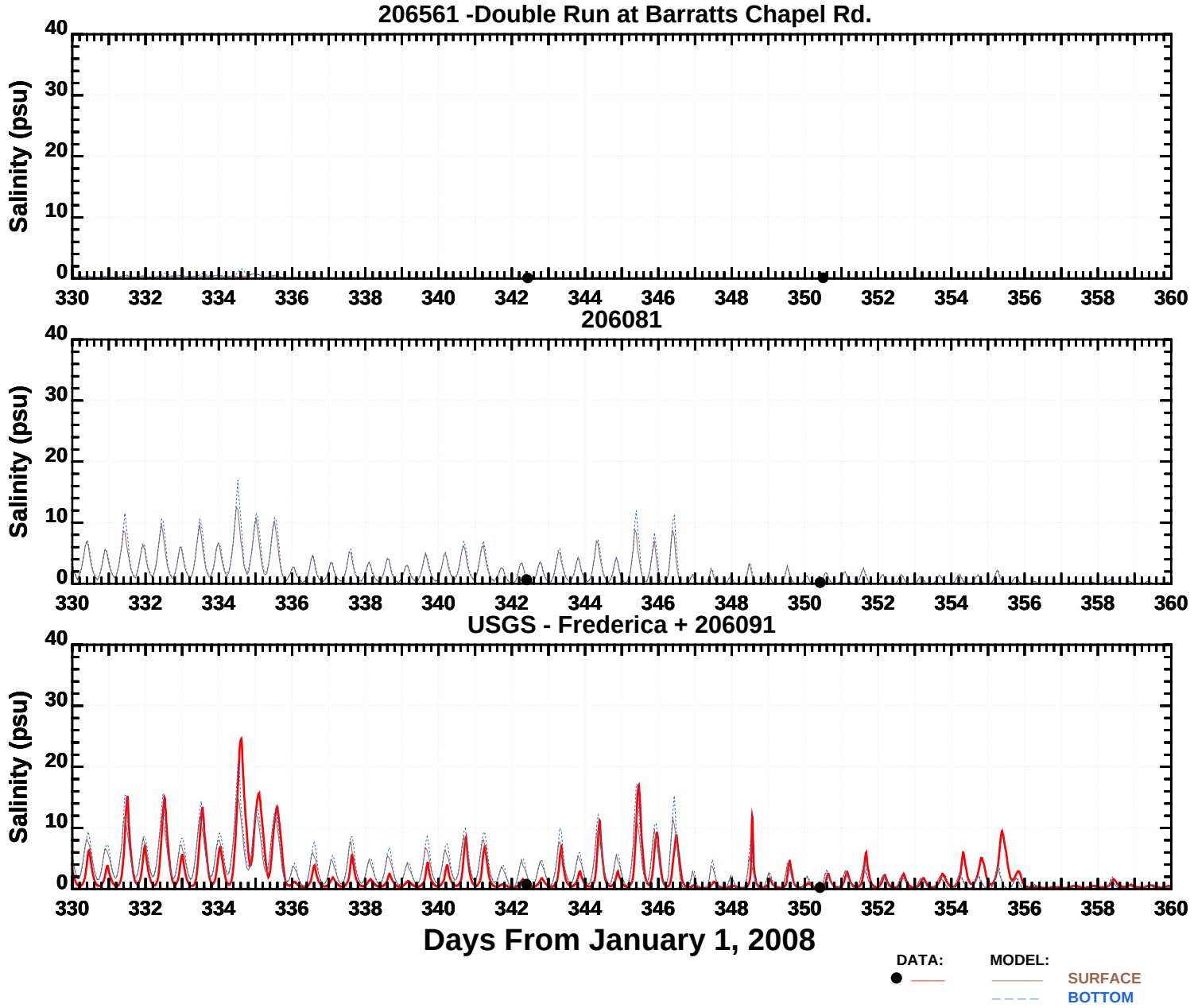

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
300
302
304
306
308
310
312
314
316
318
320
322
324
326
328
330
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

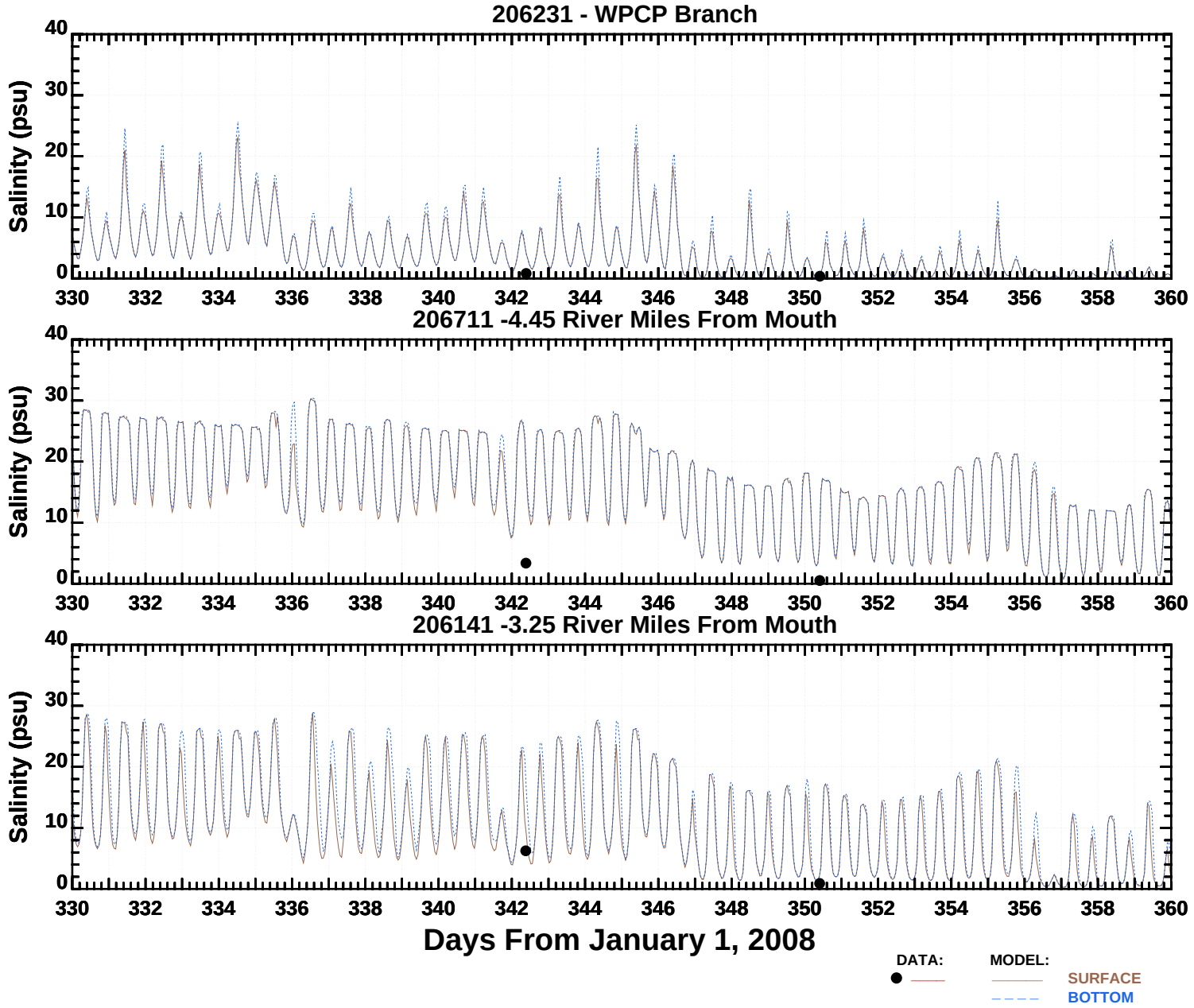
MODEL: ——— SURFACE

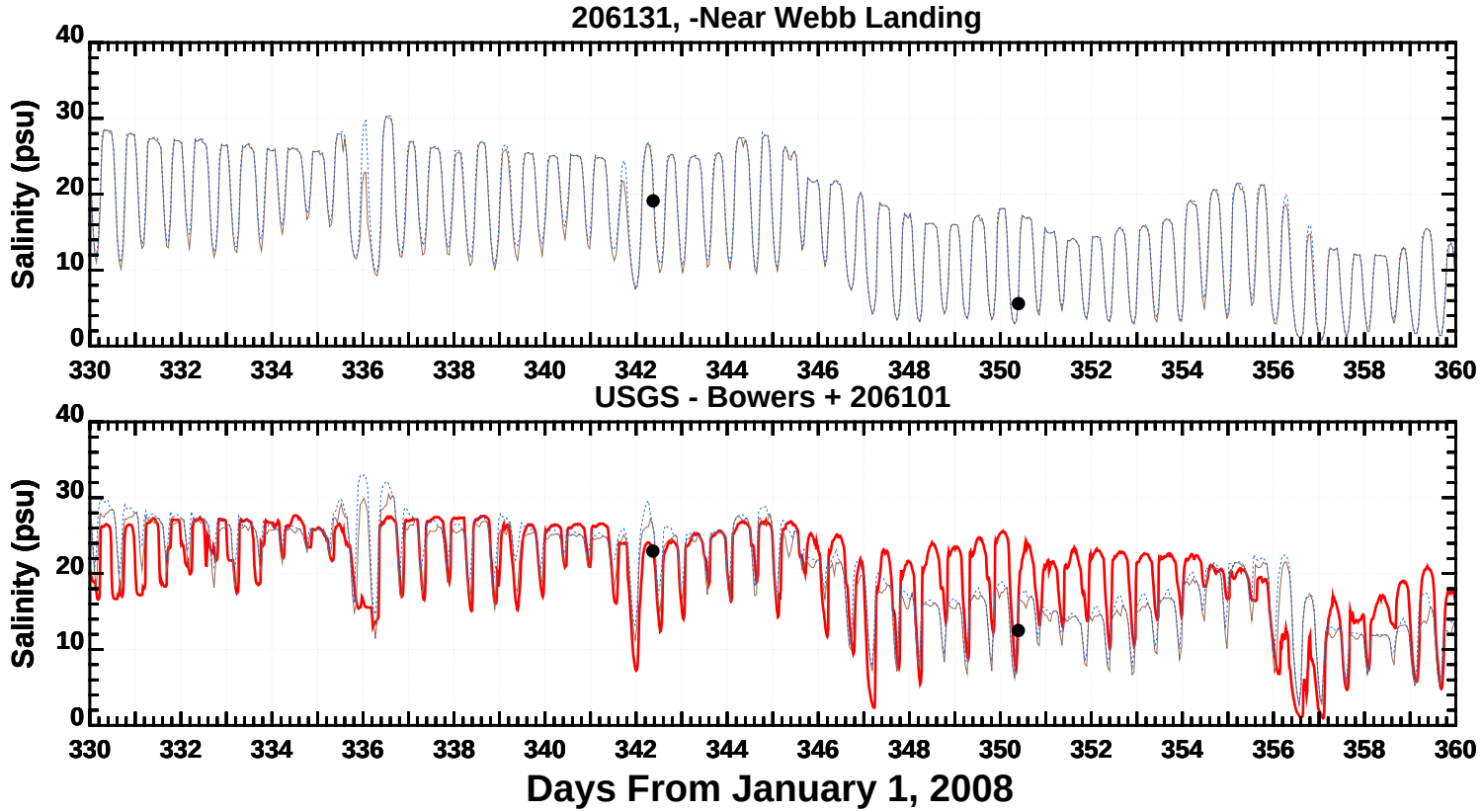
– – – – BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/saltReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:15:27


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Salinity (psu)
0
10
20
30
40
330
332
334
336
338
340
342
344
346
348
350
352
354
356
358
360
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

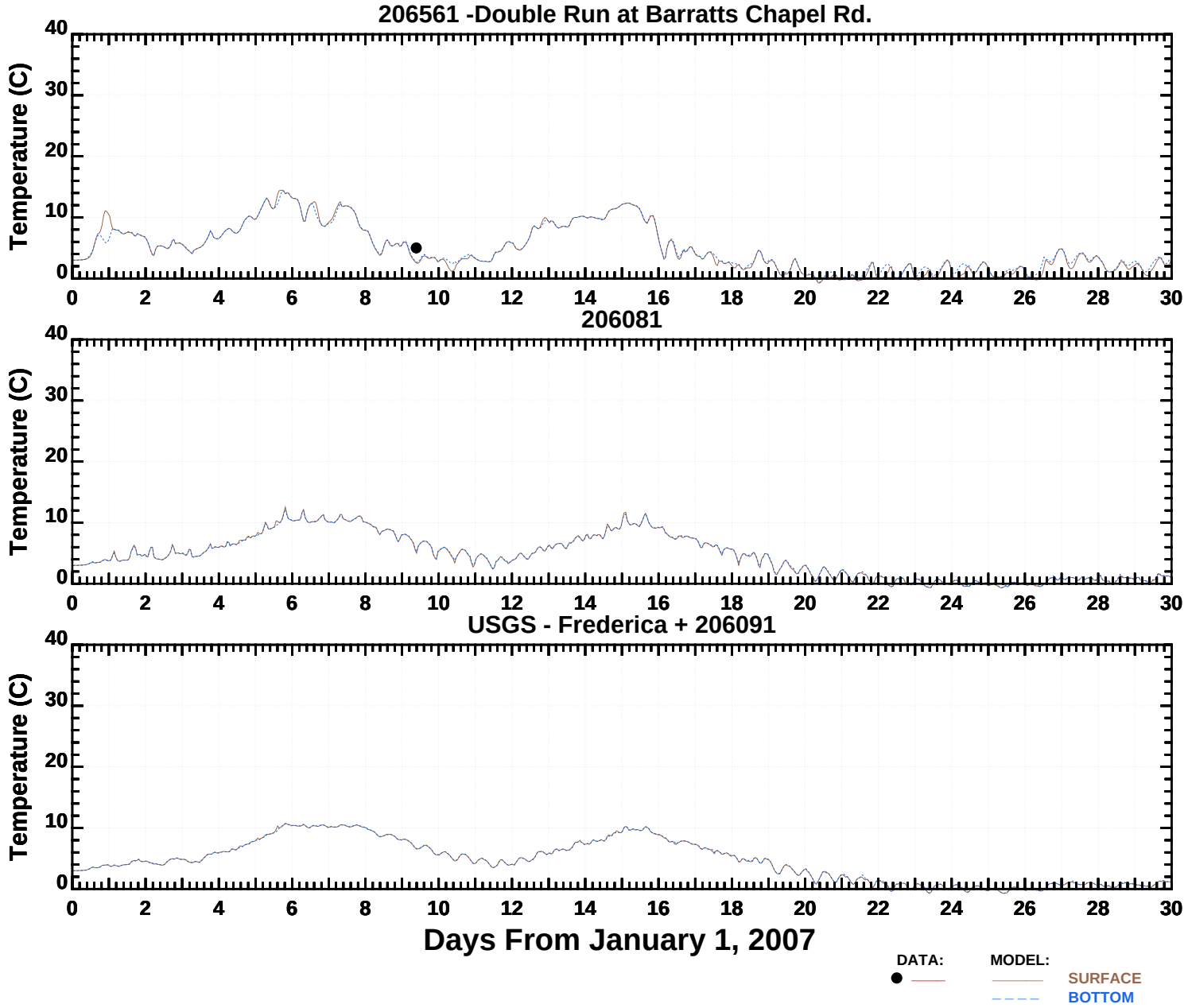


DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM

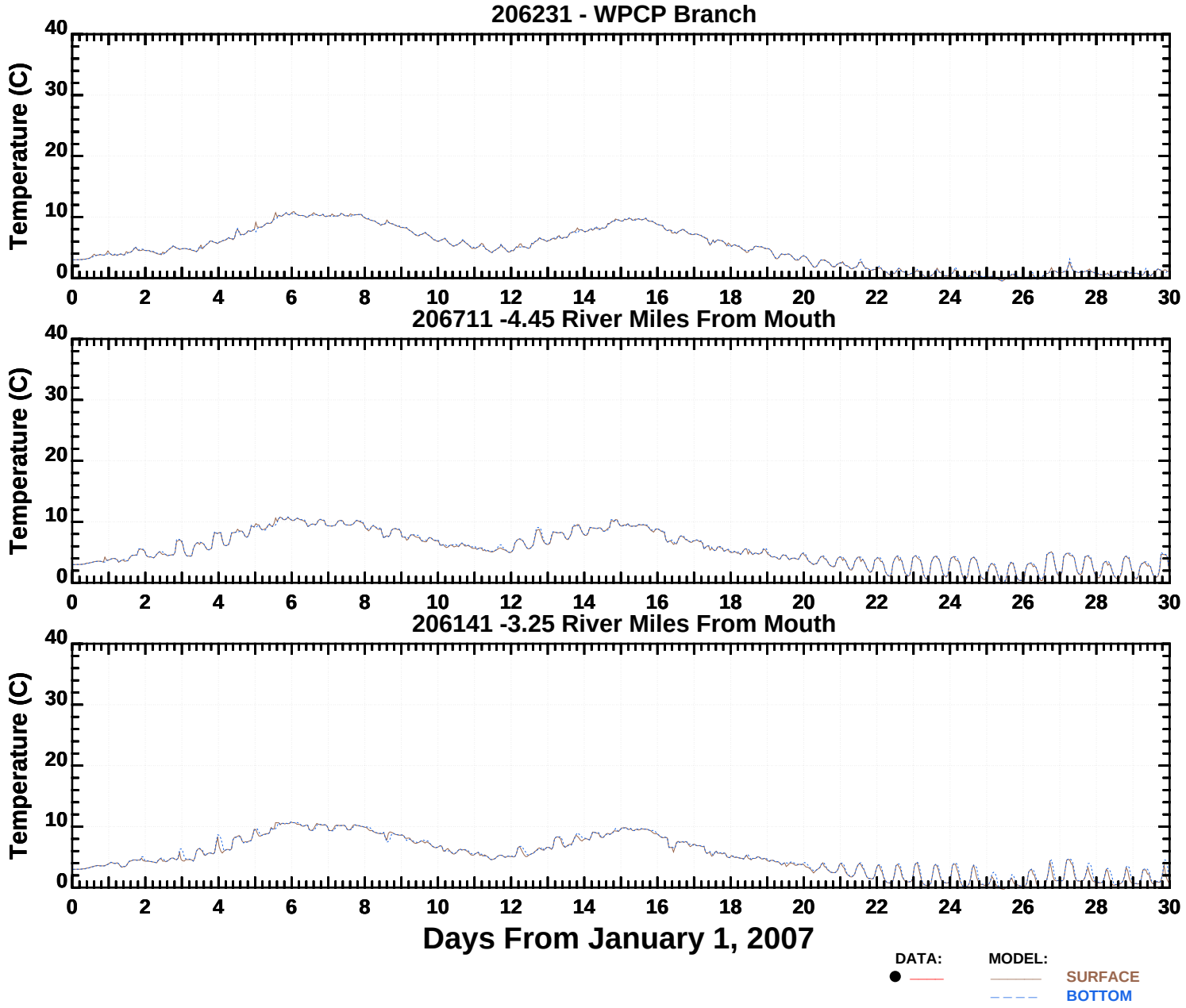
DATE: 1/22/2013 TIME: 13:15:27

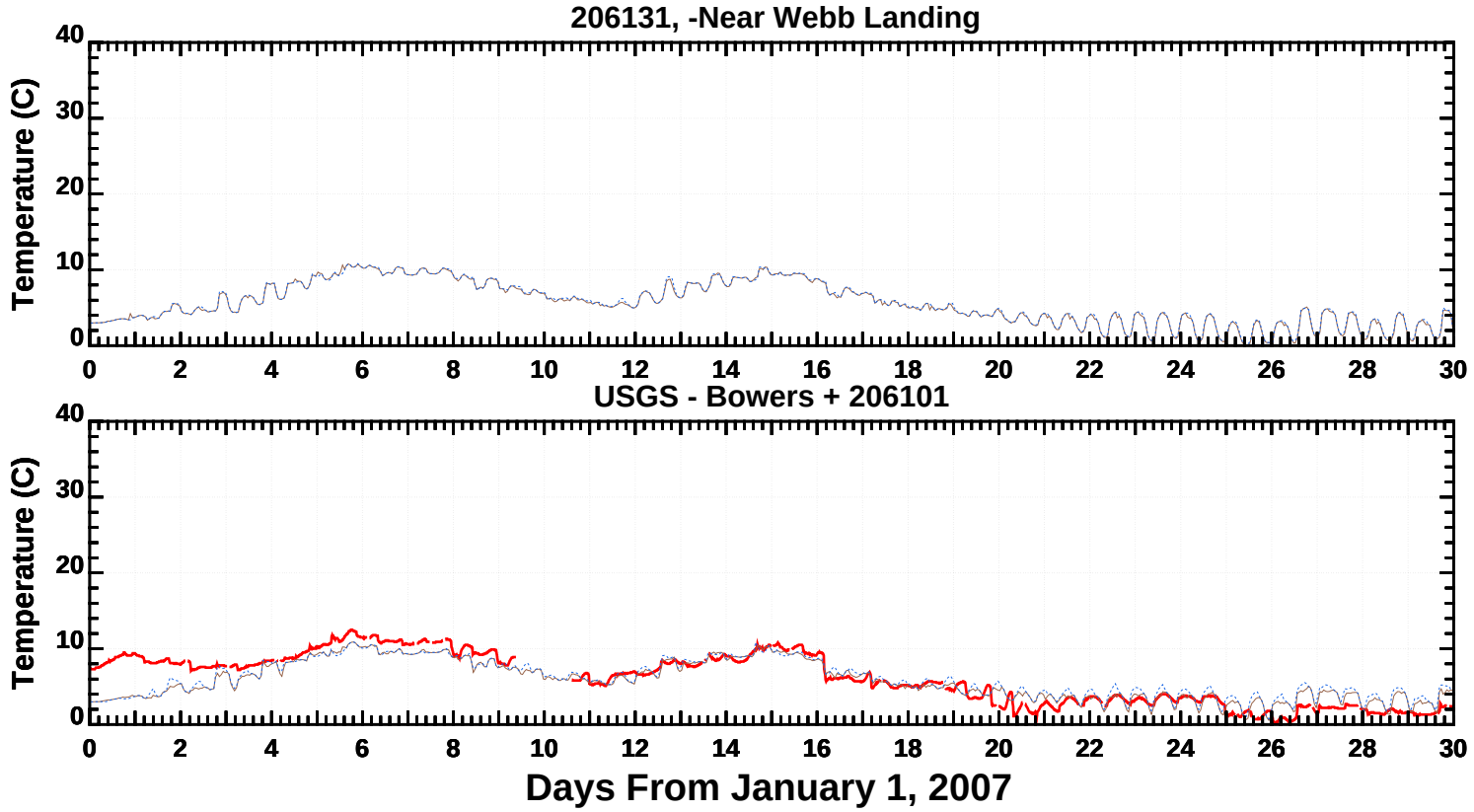


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:12:30

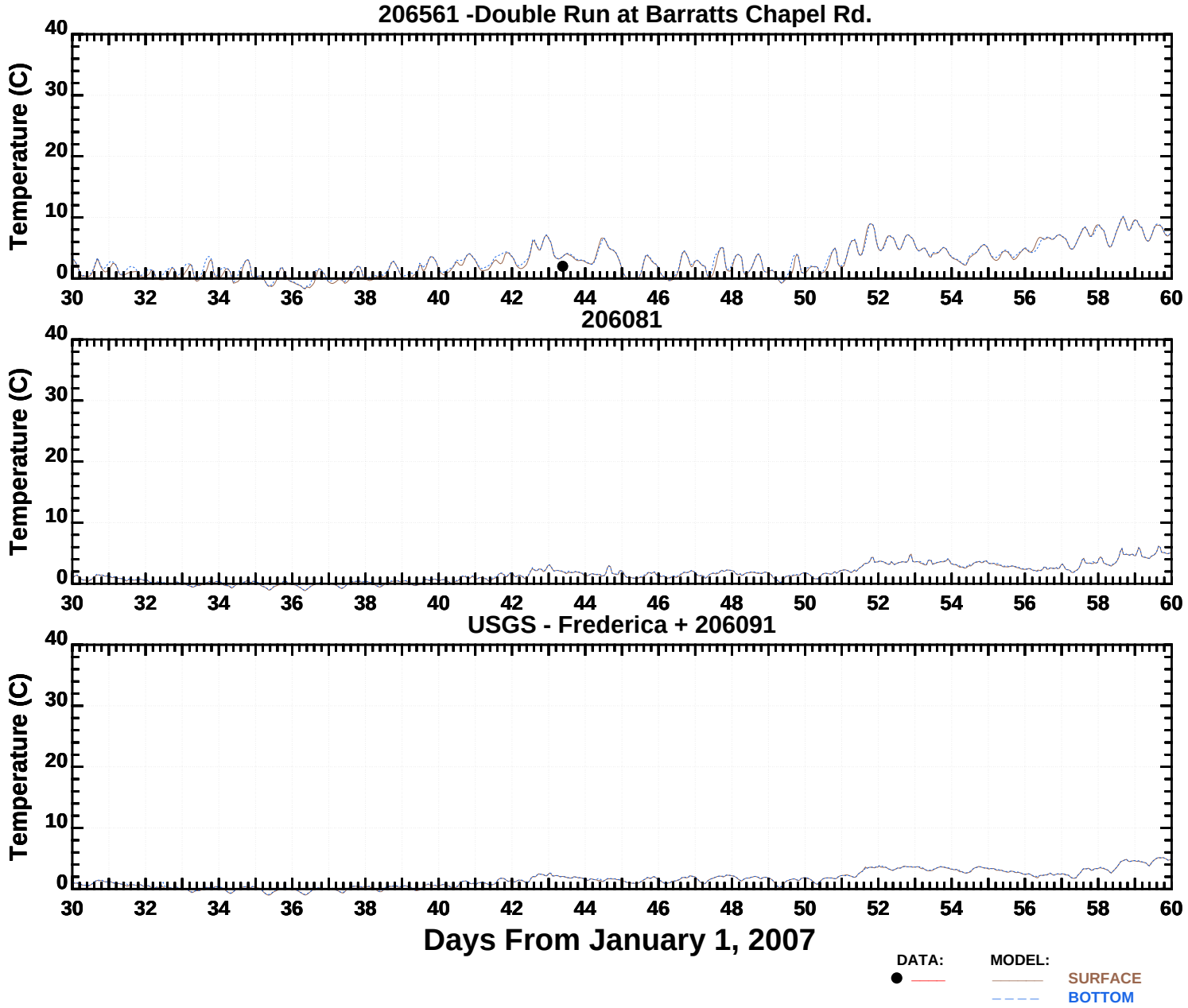

206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

MODEL: ——— SURFACE

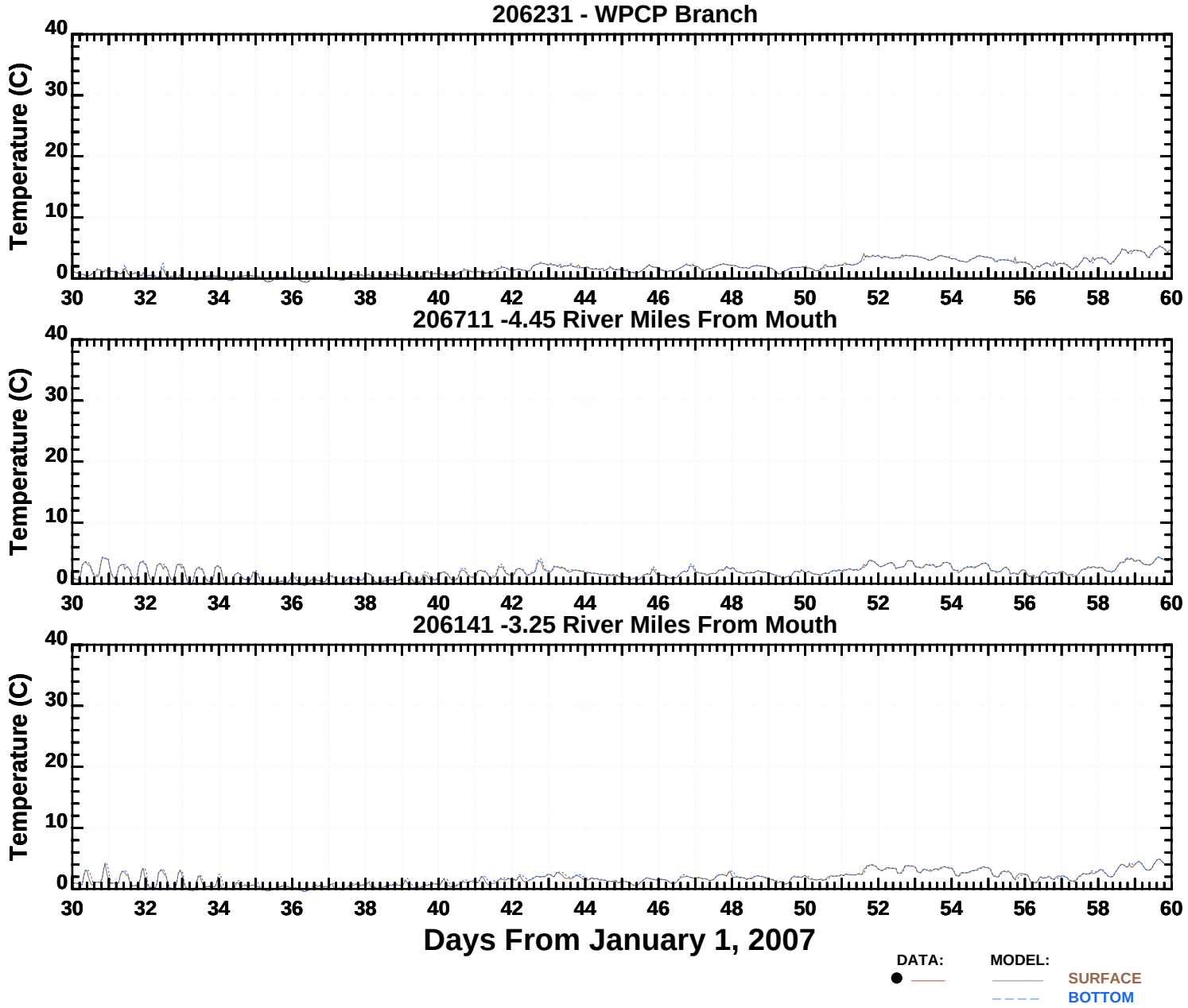
– – – – BOTTOM

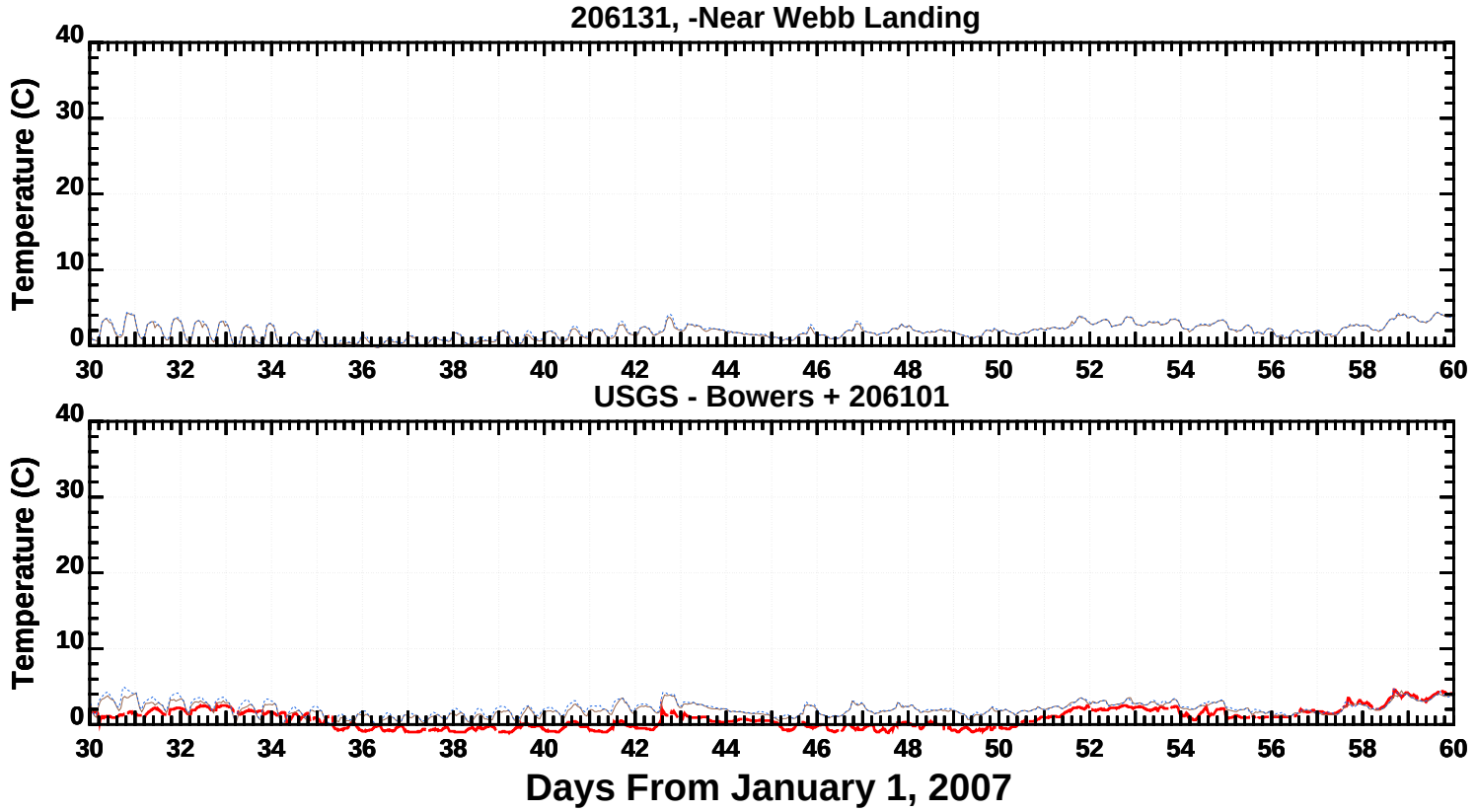


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

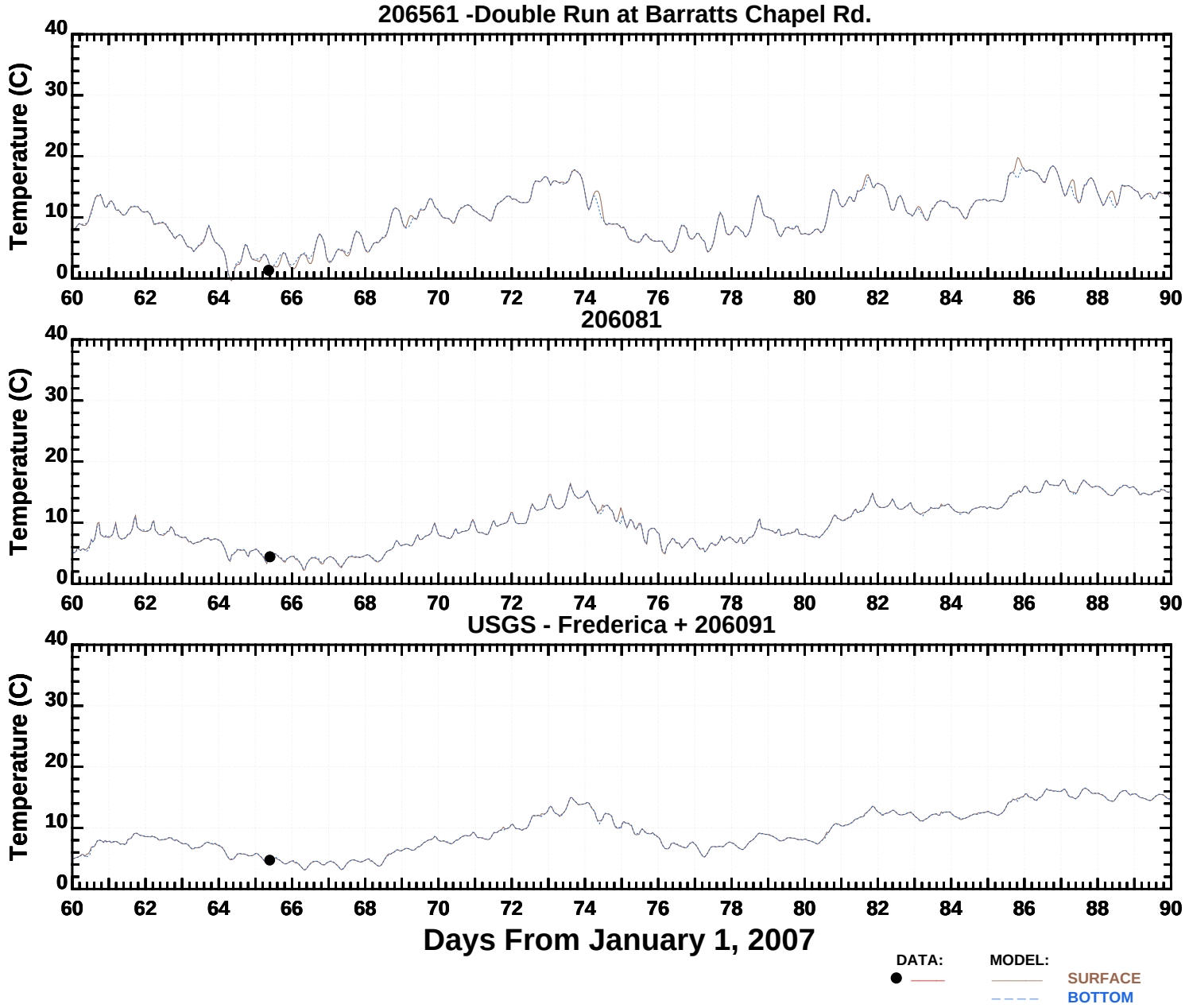
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:12:38


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



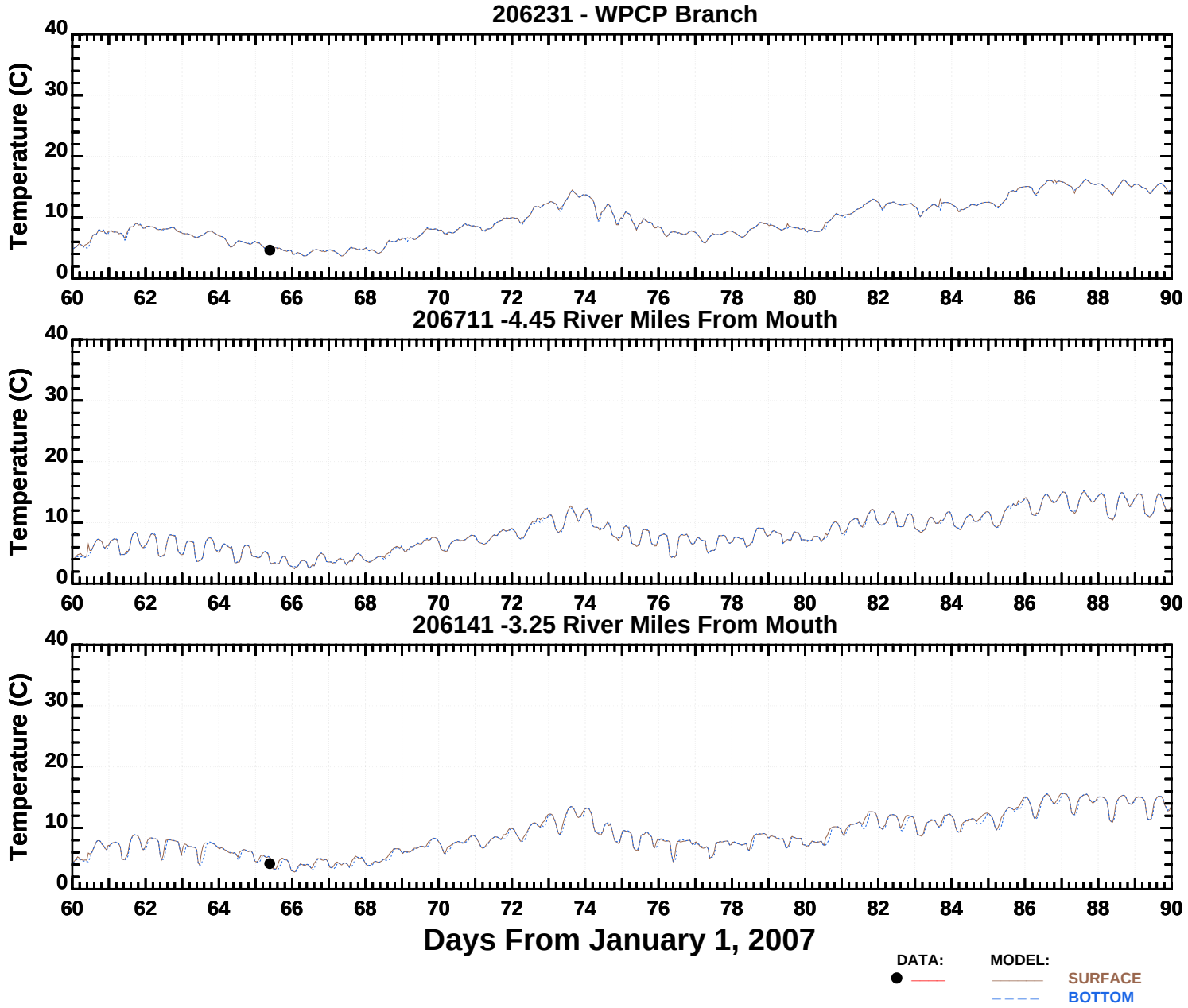
DATA: MODEL:
SURFACE
BOTTOM

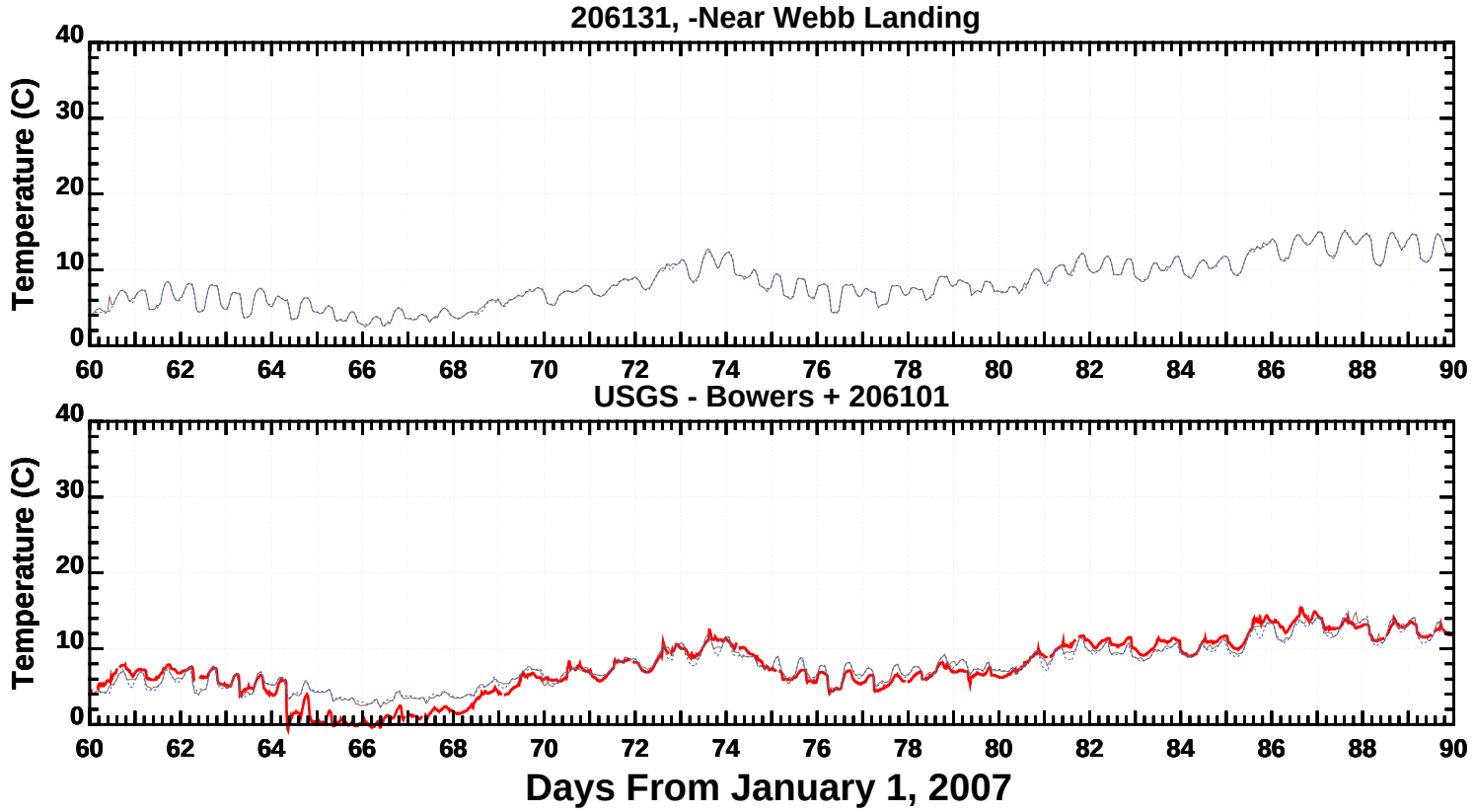


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

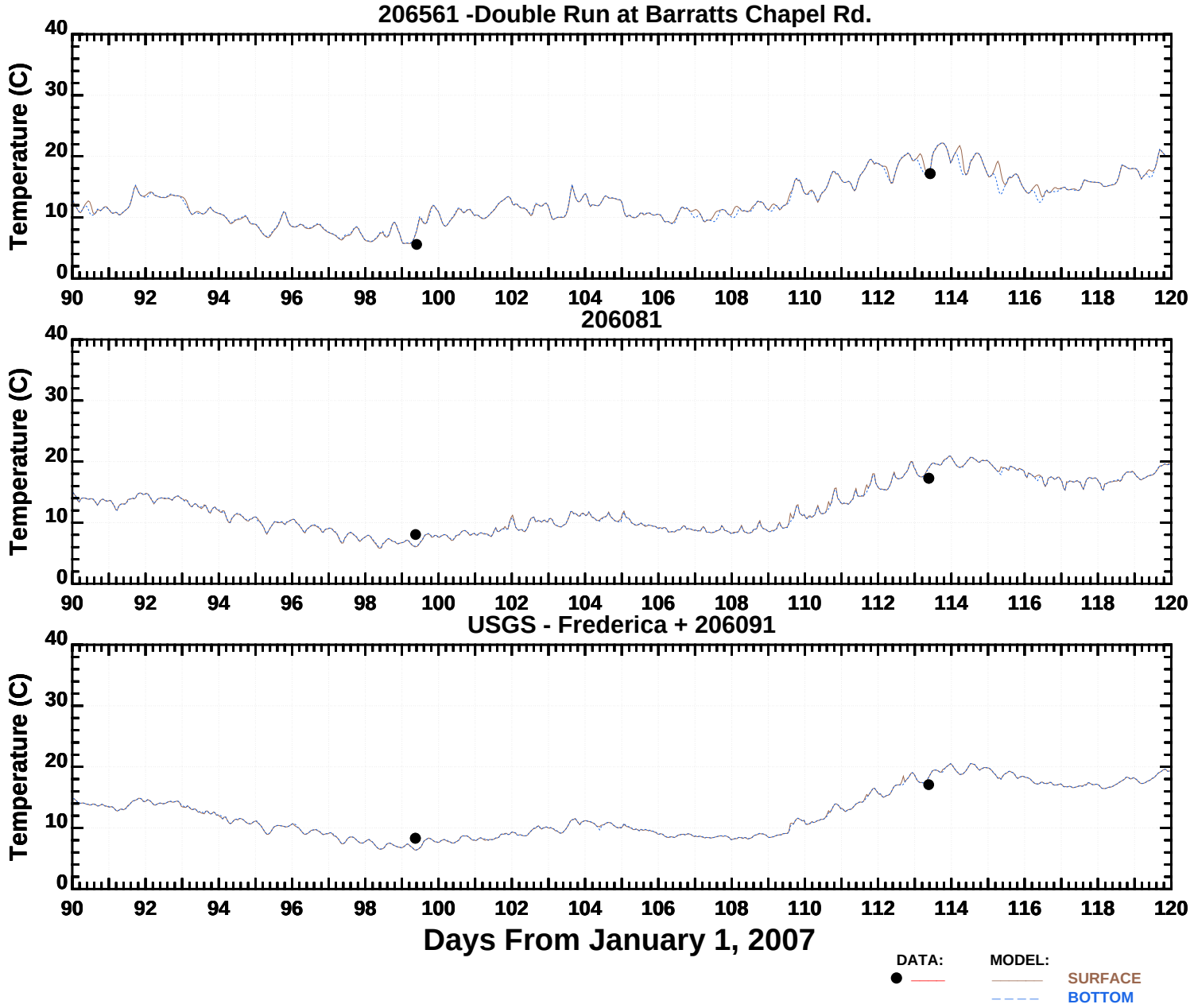
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:12:45


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



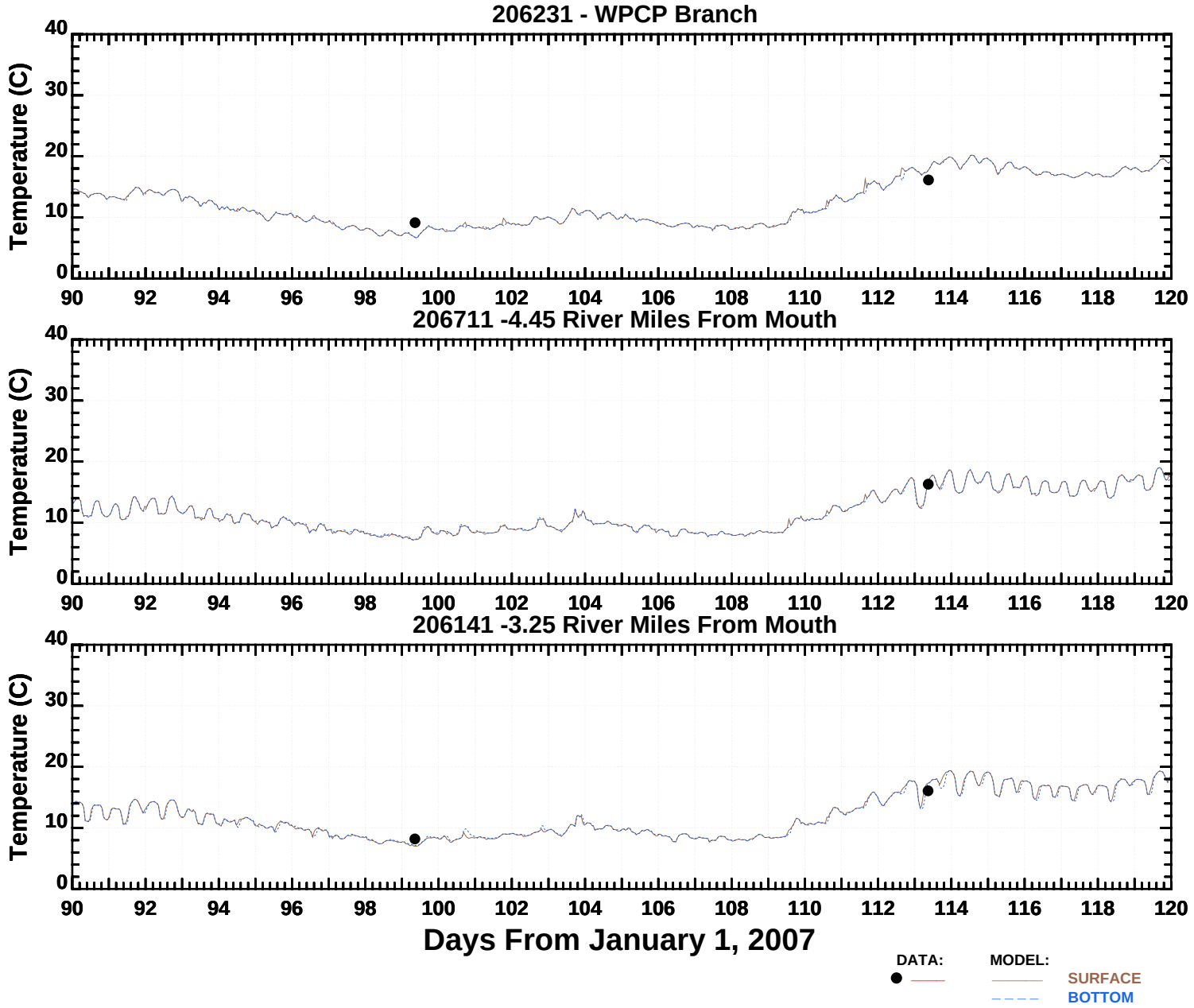
DATA: MODEL:
SURFACE
BOTTOM

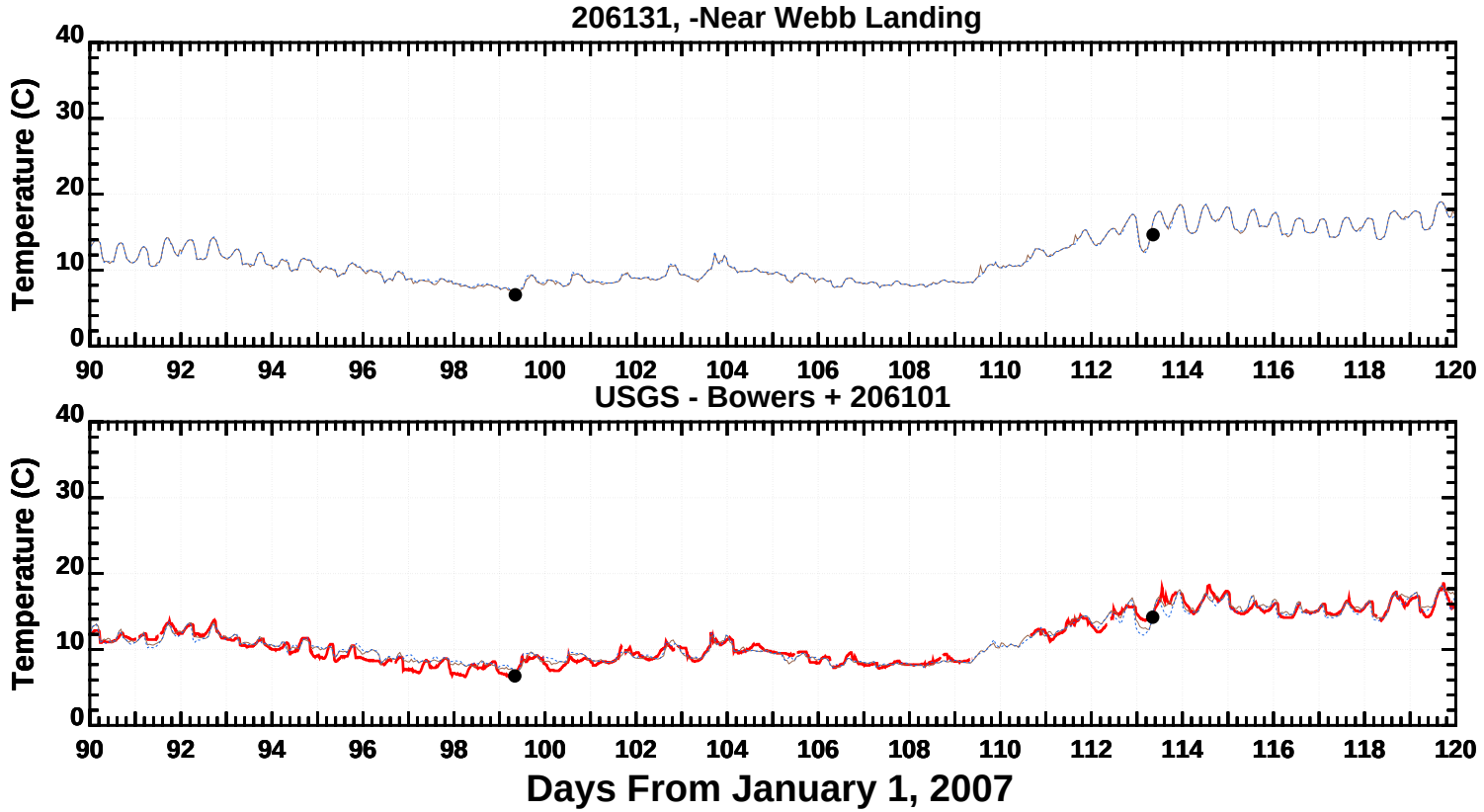


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:12:52

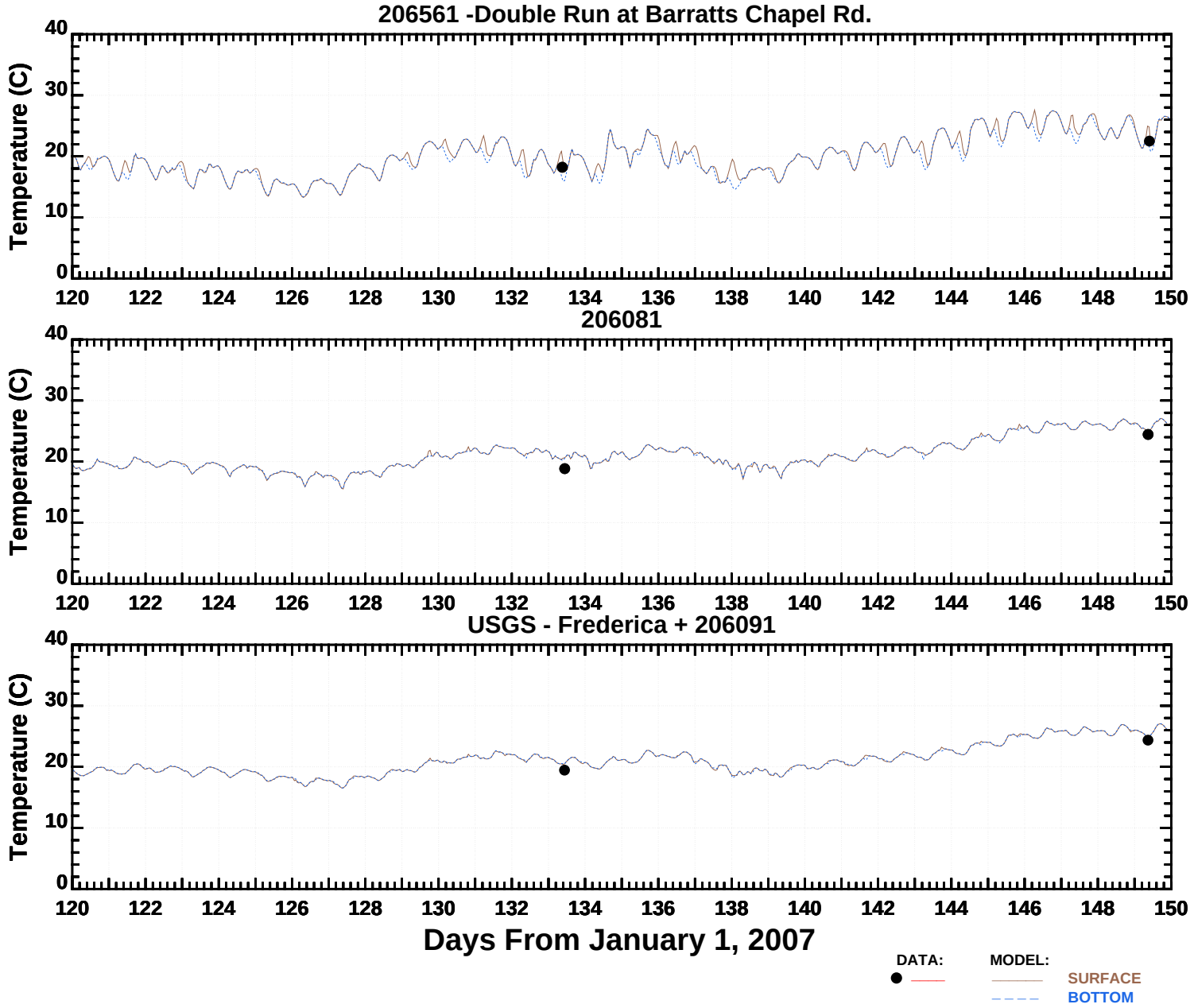

206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

MODEL: ——— SURFACE

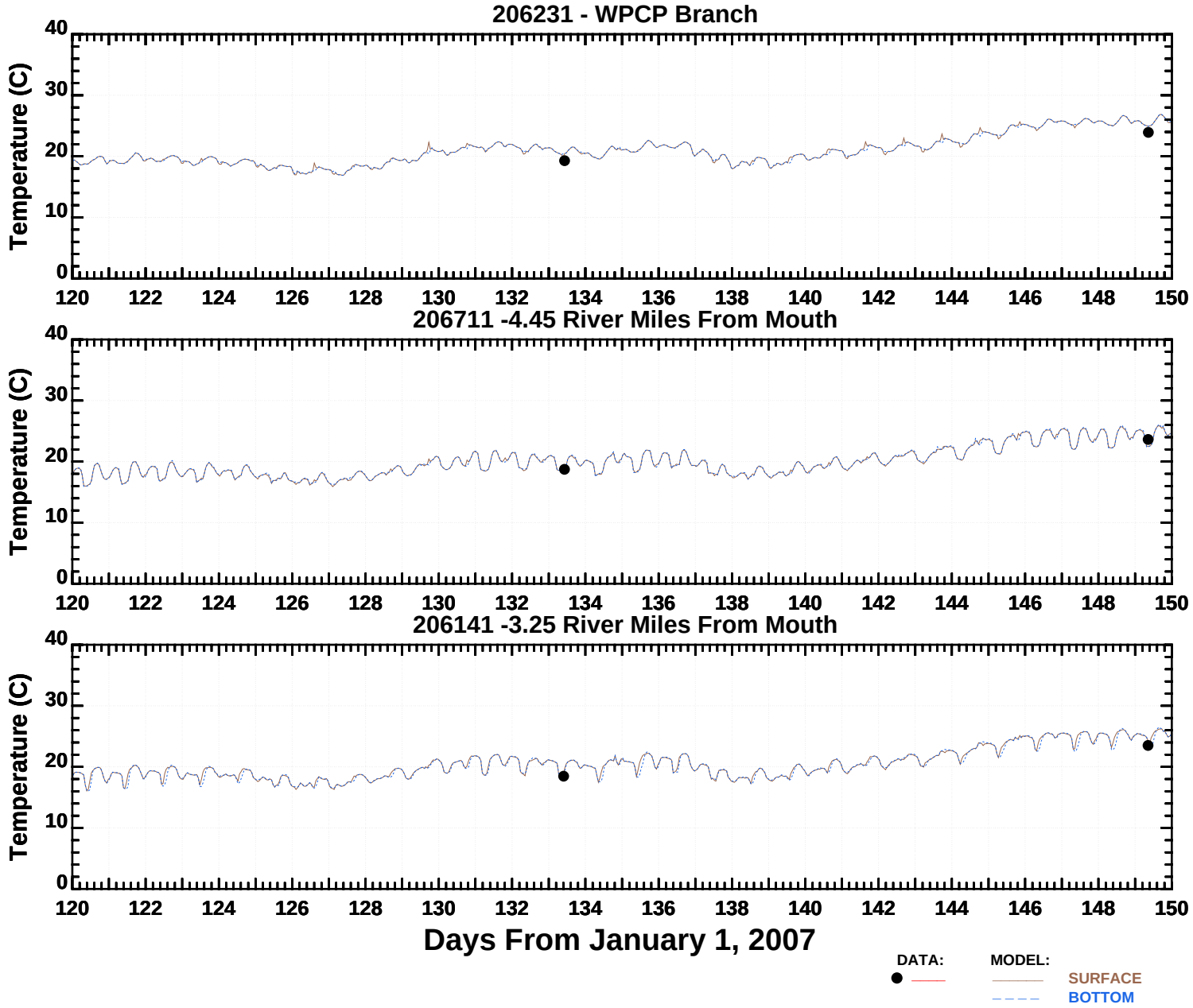
– – – – BOTTOM

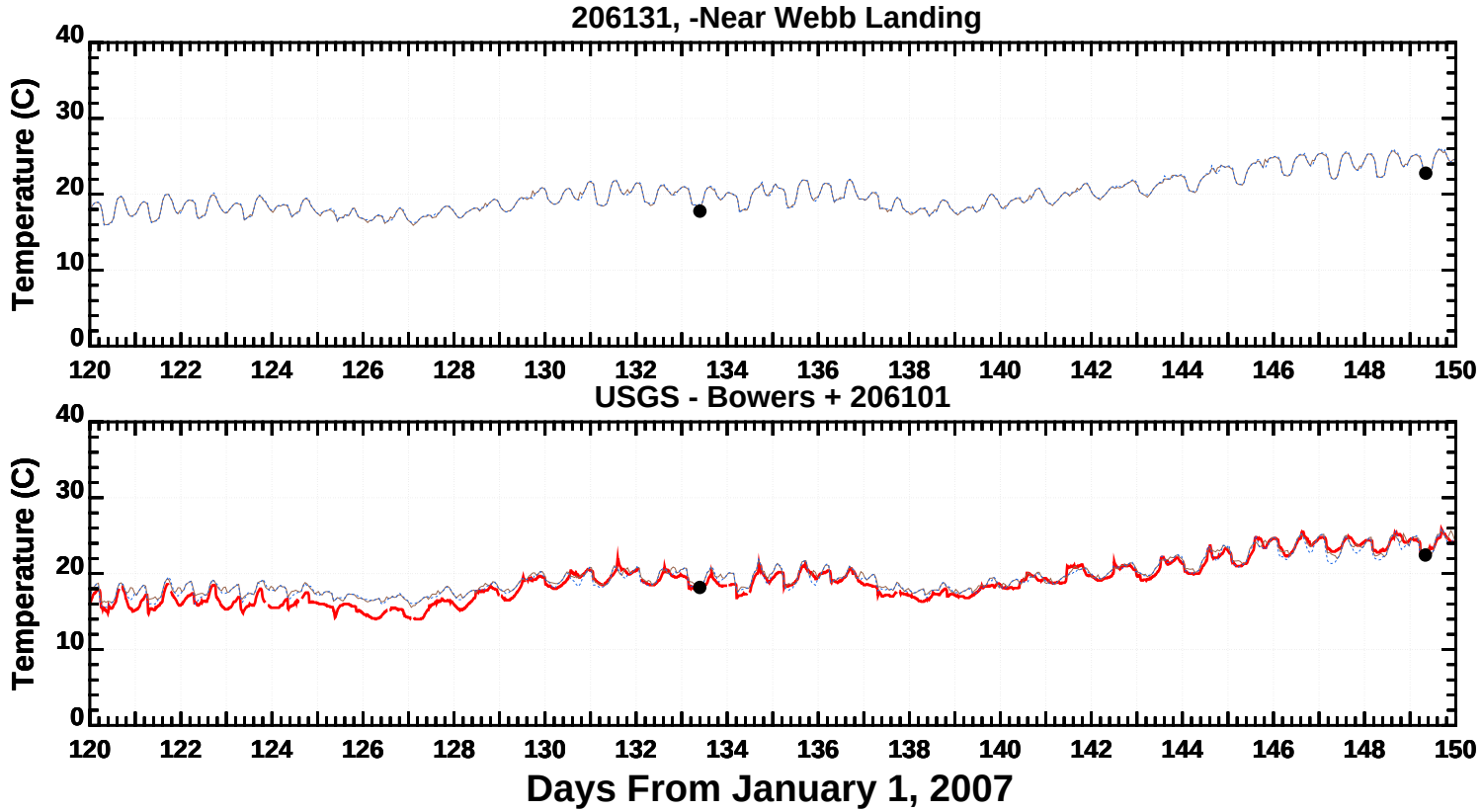


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13: 0

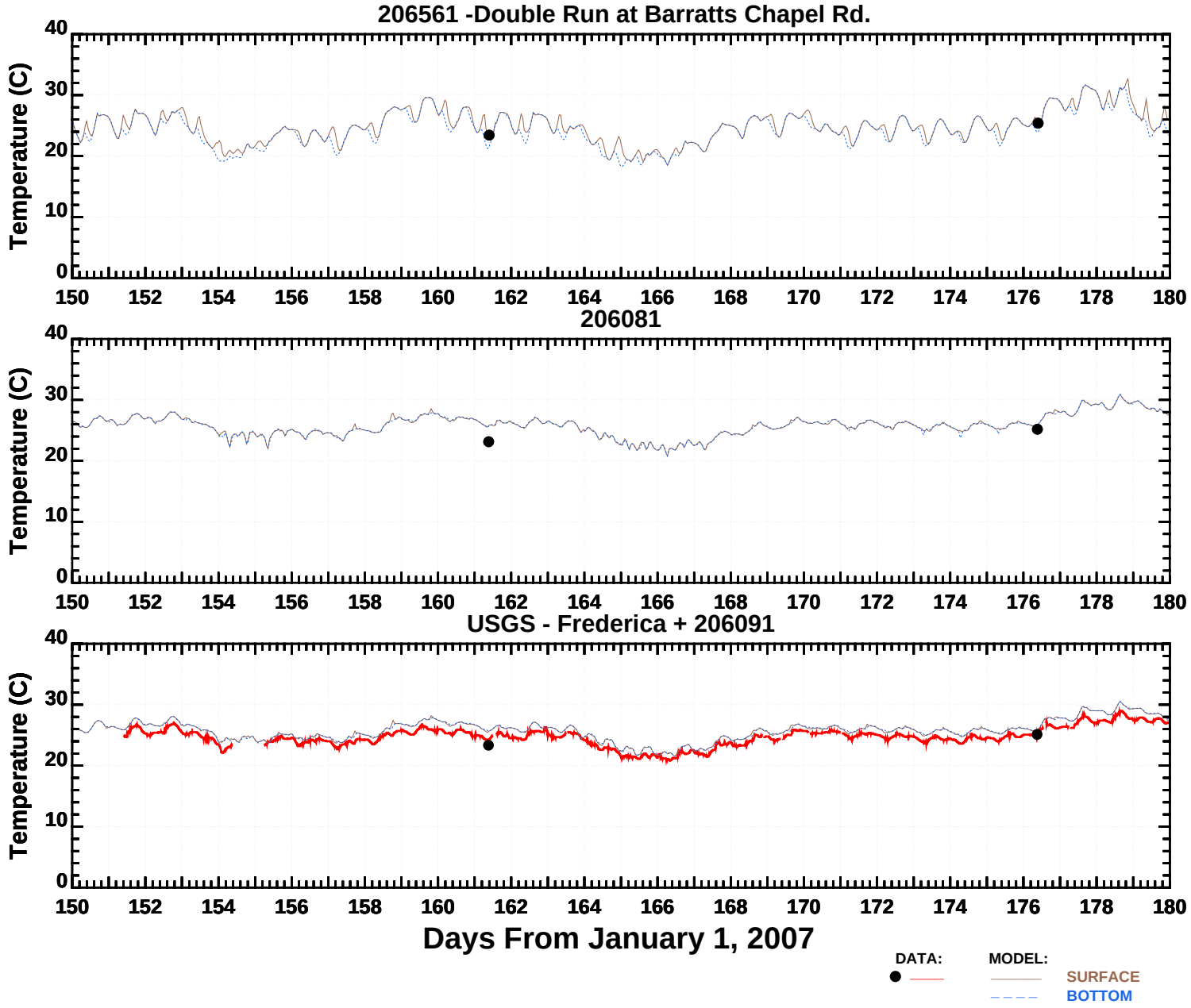

206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: MODEL:
SURFACE
BOTTOM

DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 3 of 3
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

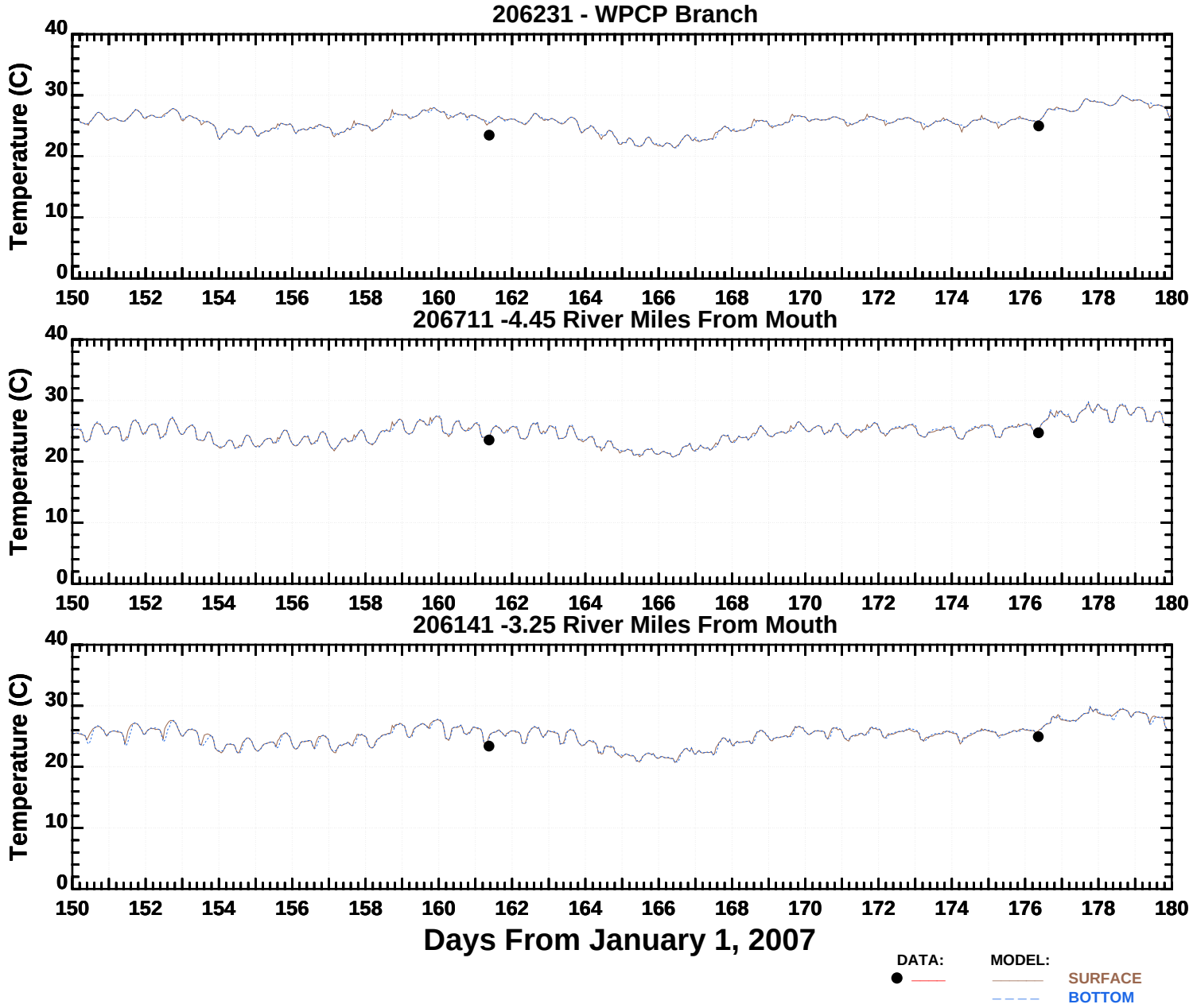
DATE: 1/22/2013 TIME: 13:13: 0

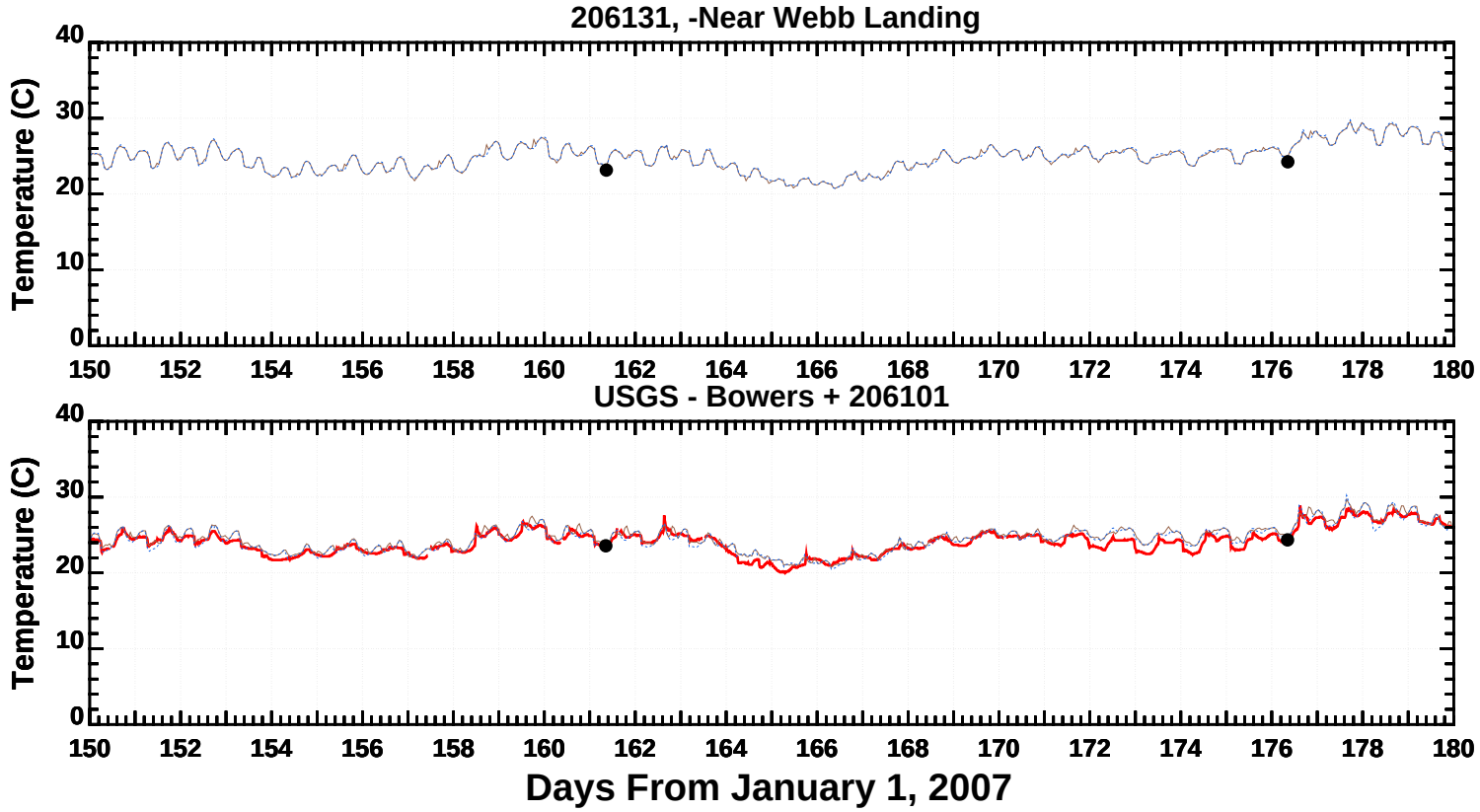


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

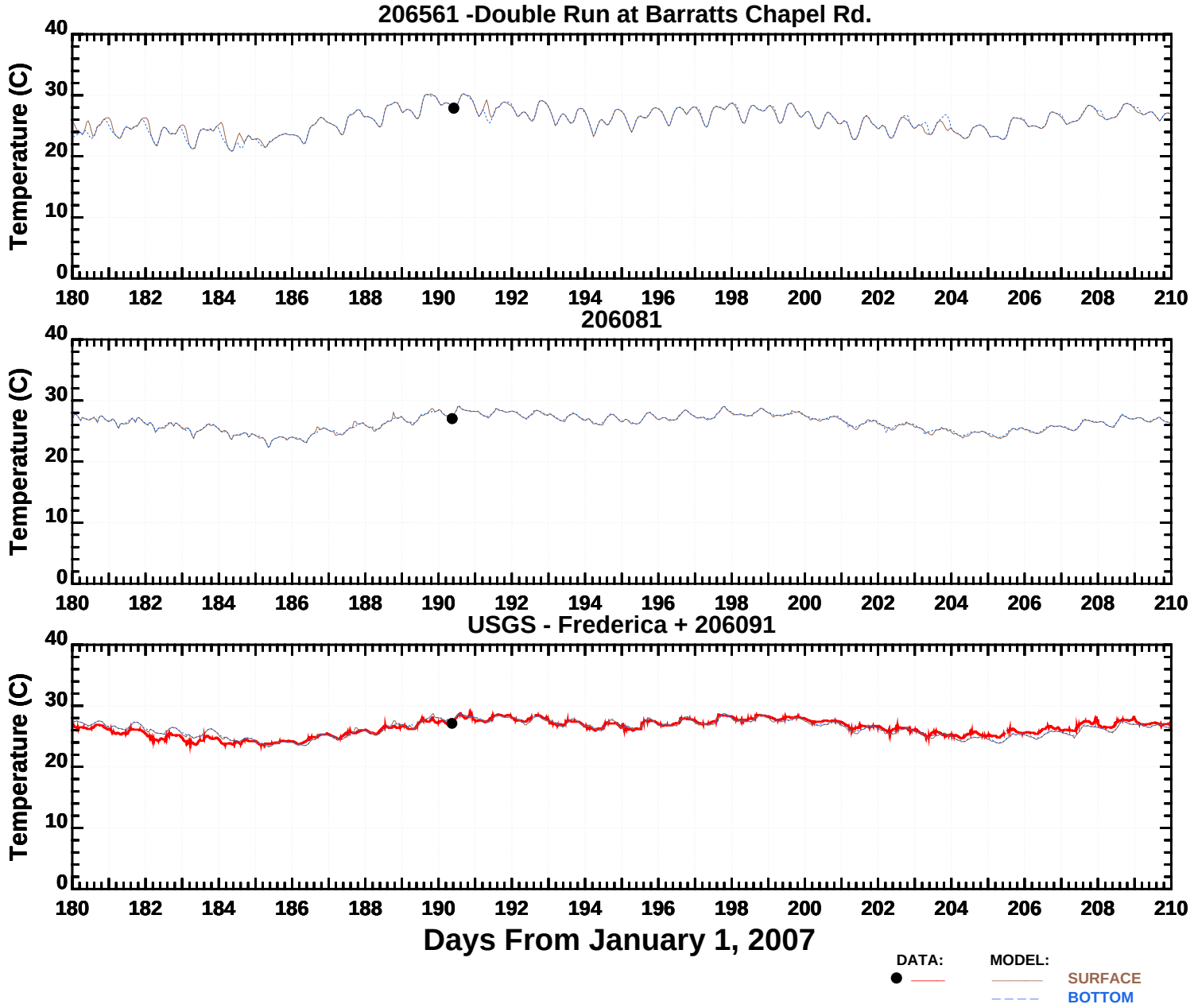
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13: 8


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM

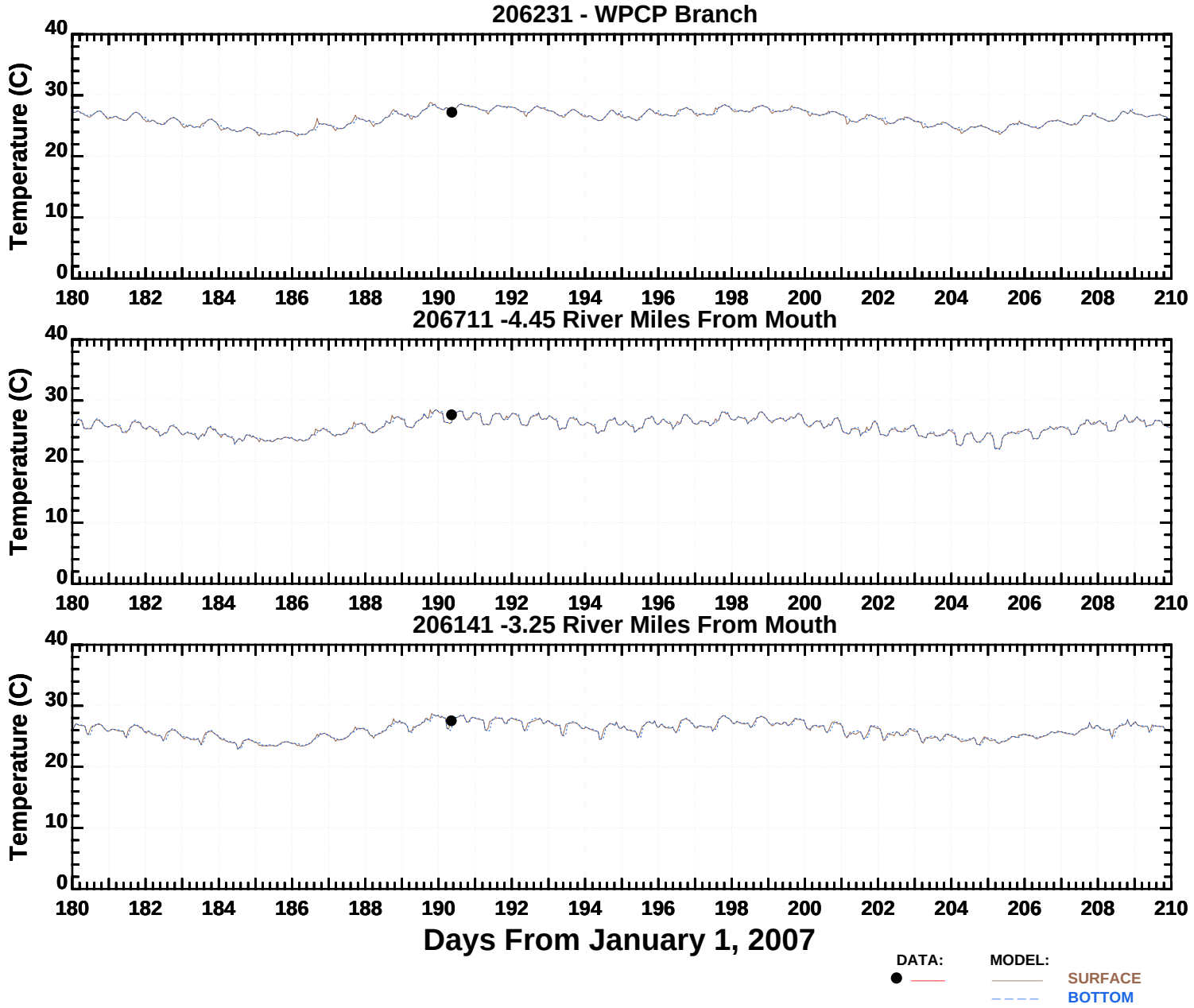


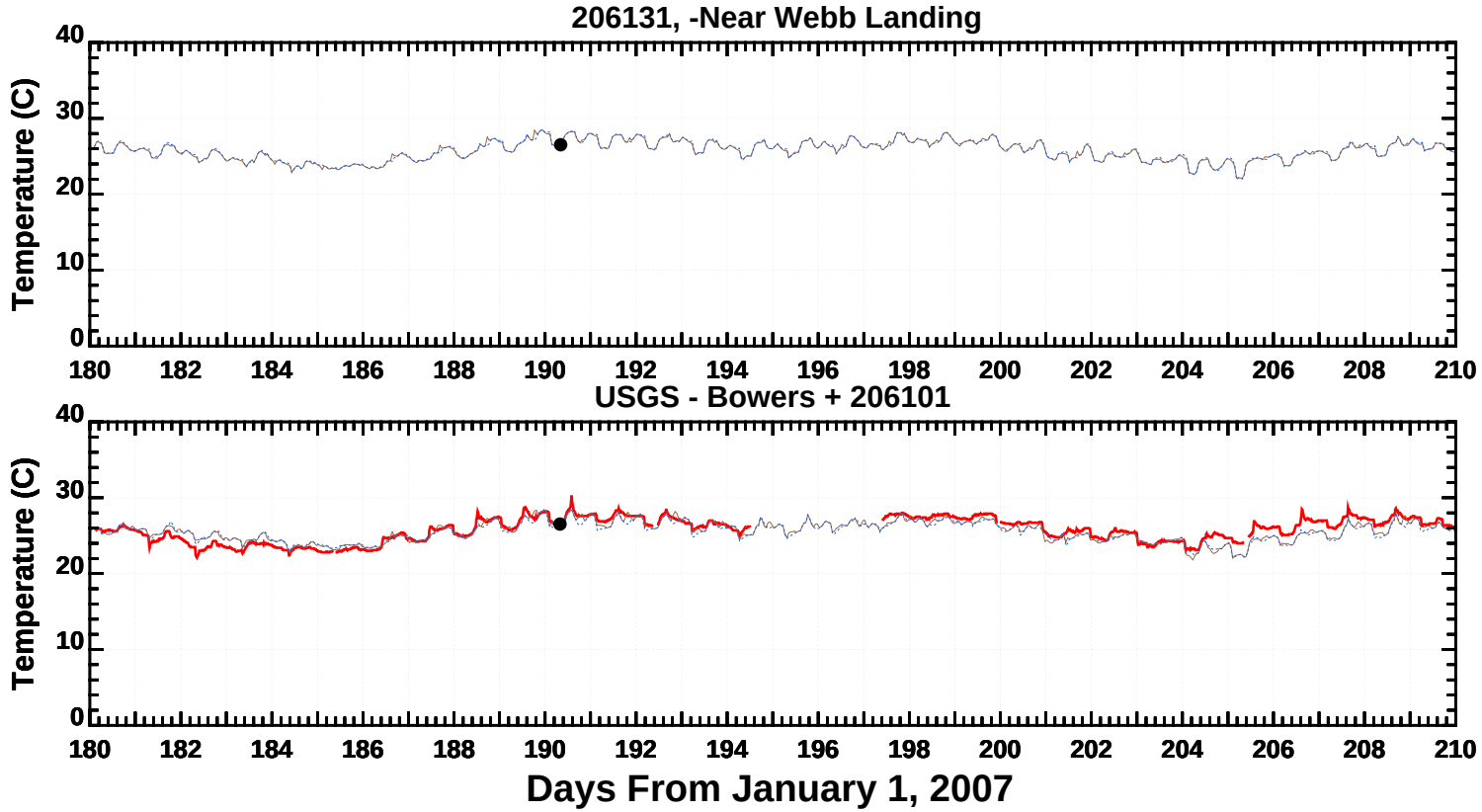
DATA: ● MODEL: SURFACE BOTTOM



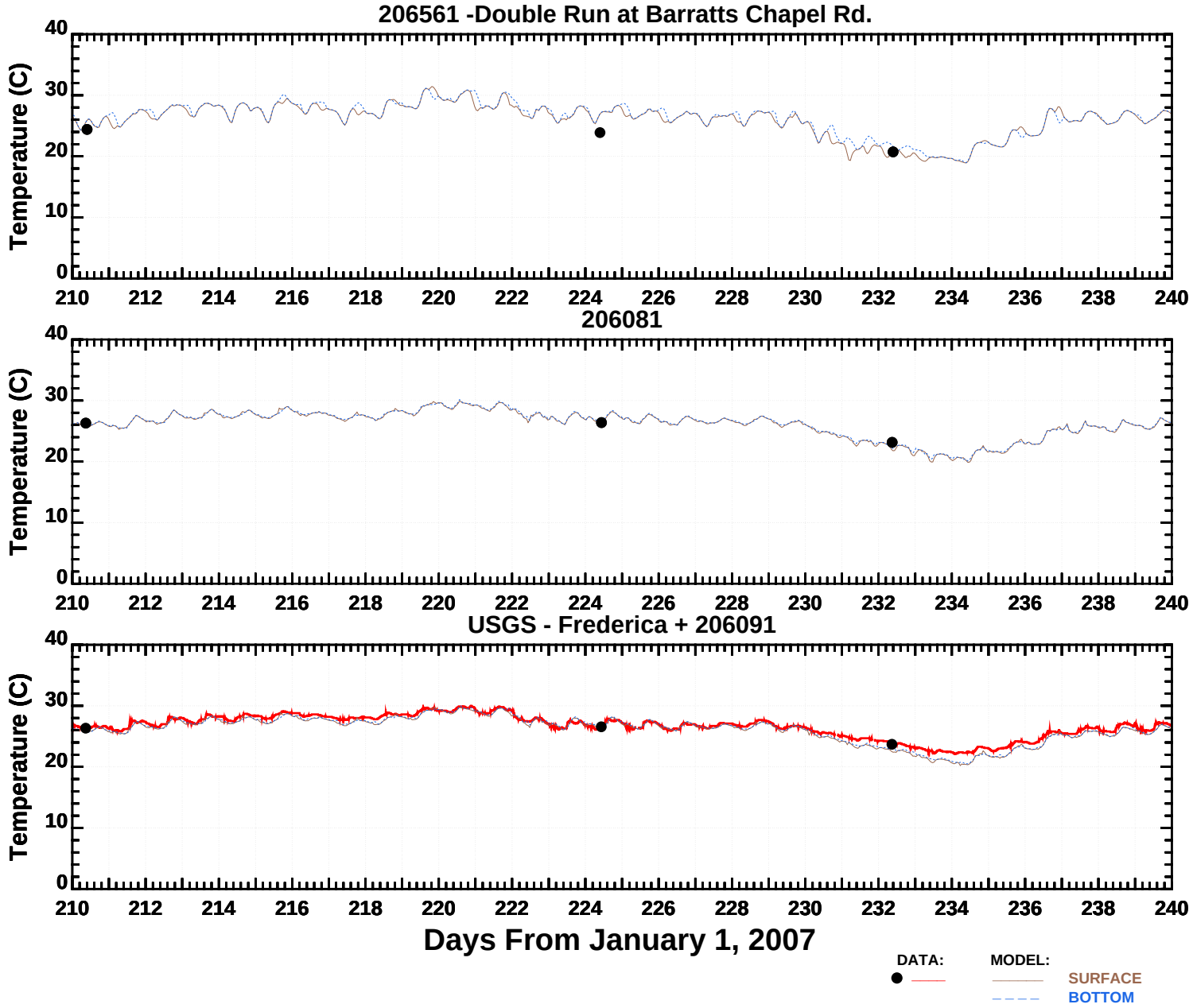
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 1 of 3
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13:15


206231 - WPCP Branch
Temperature (C)
0
10
20
30
40
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
206711 -4.45 River Miles From Mouth
Temperature (C)
206141 -3.25 River Miles From Mouth
Temperature (C)
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



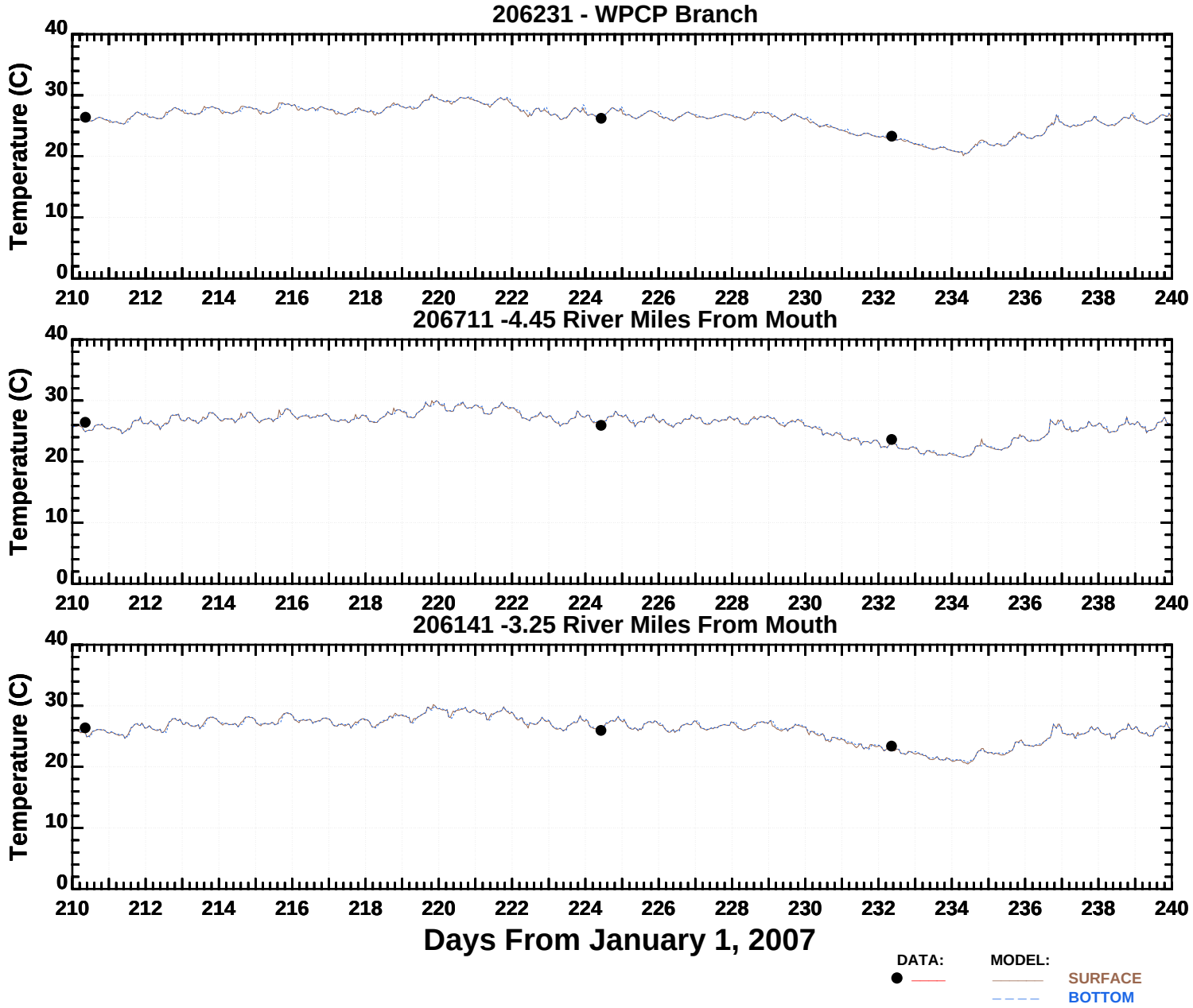
DATA: MODEL:
SURFACE
BOTTOM

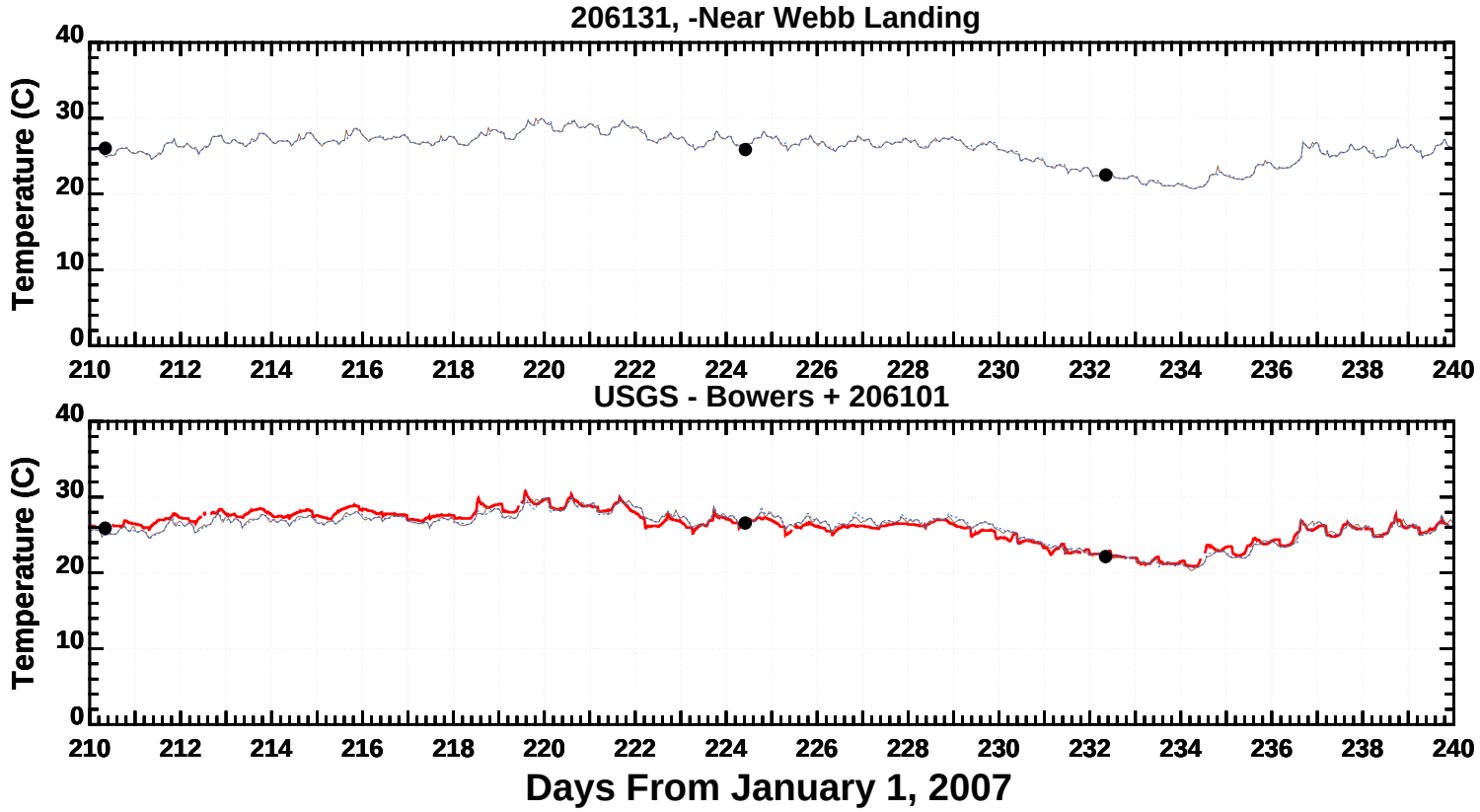


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

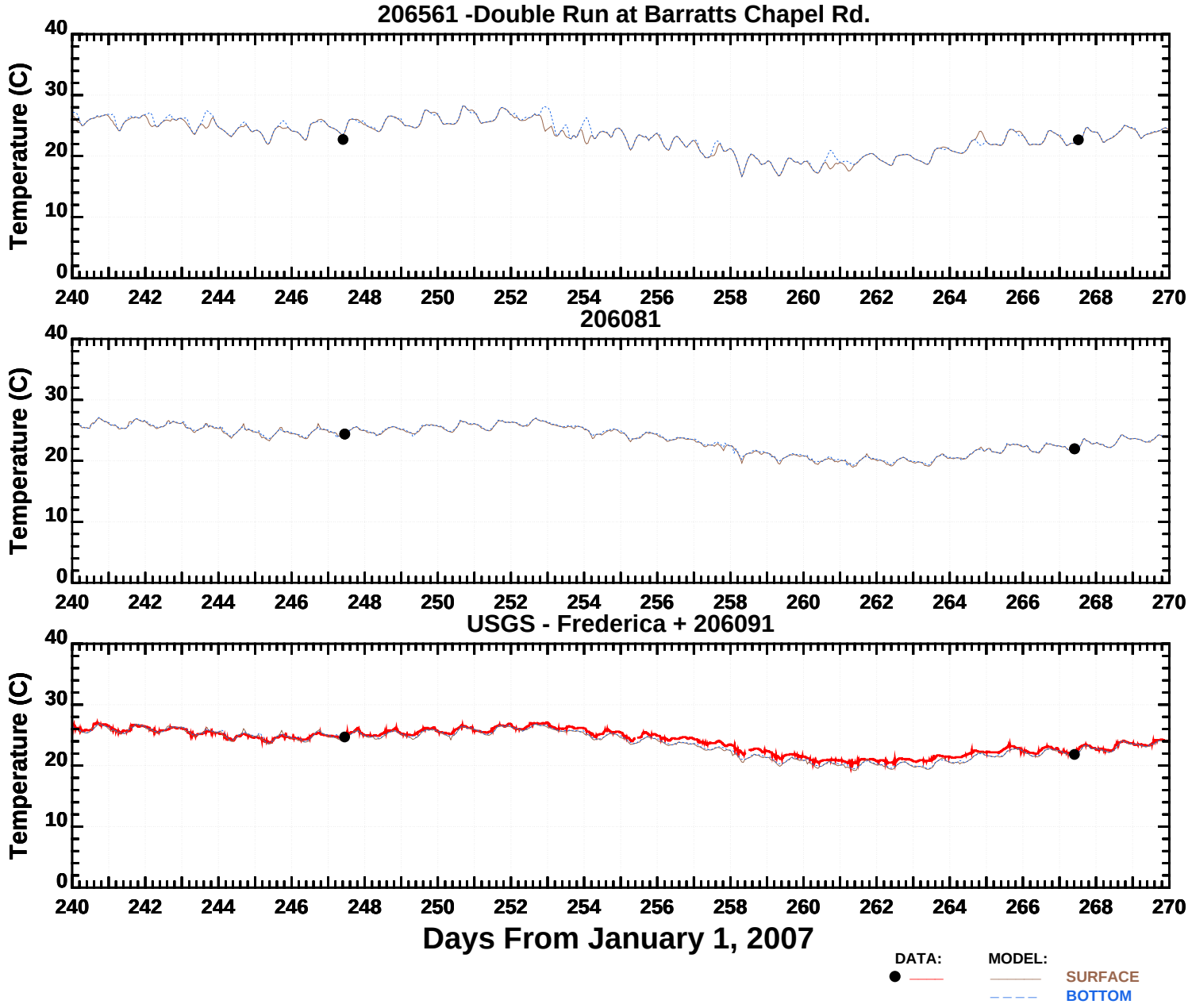
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13:23


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM

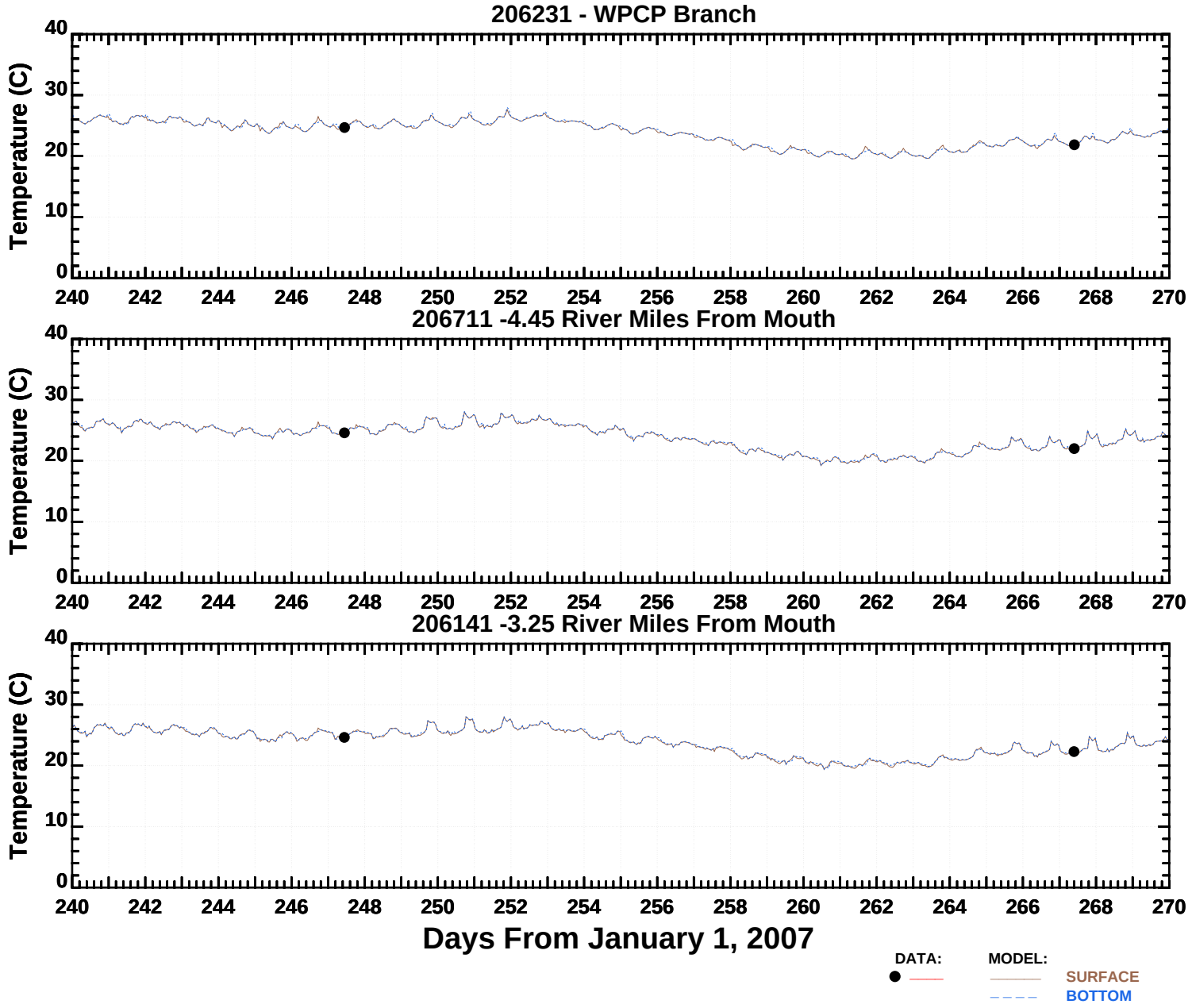


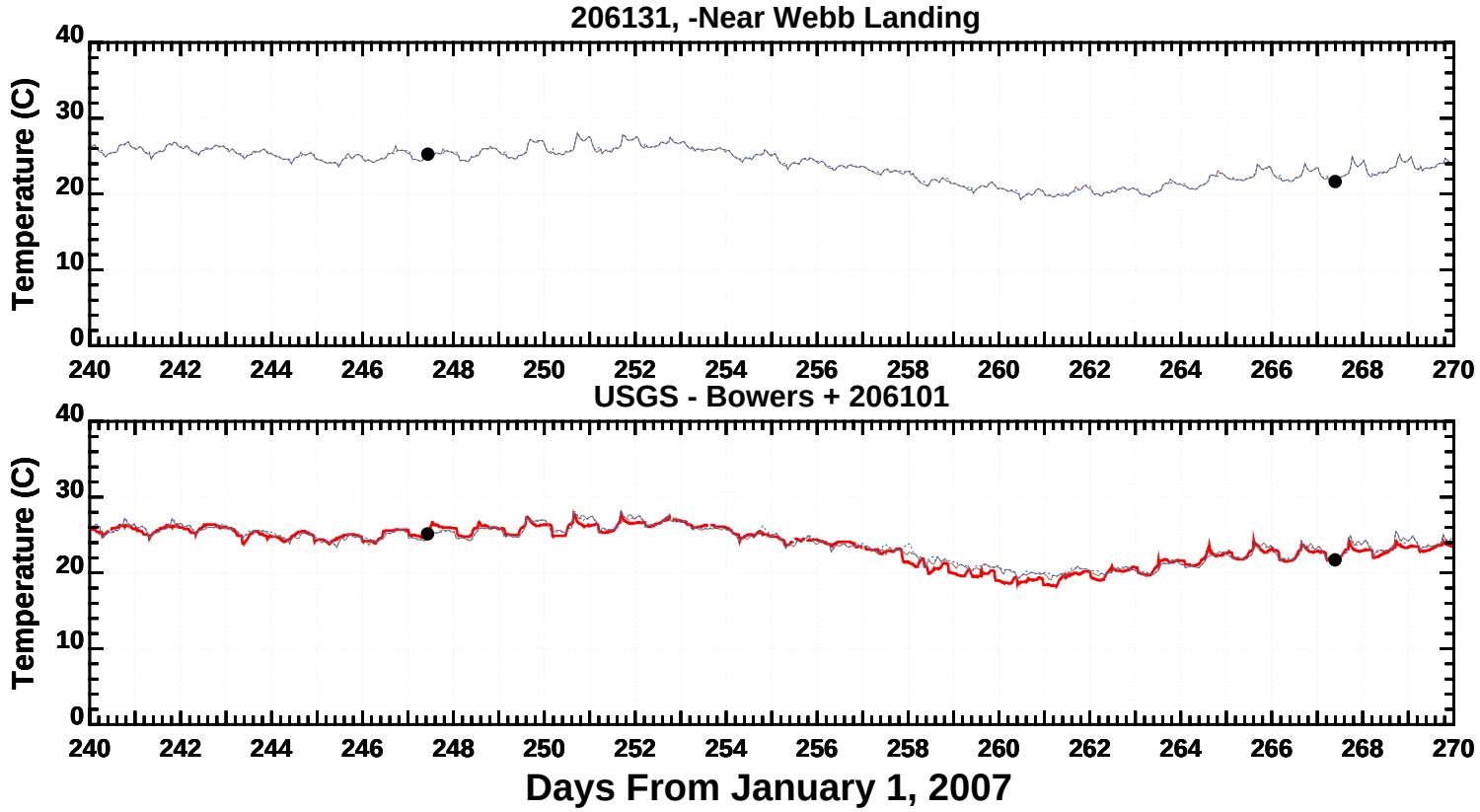
DATA: MODEL:
SURFACE
BOTTOM



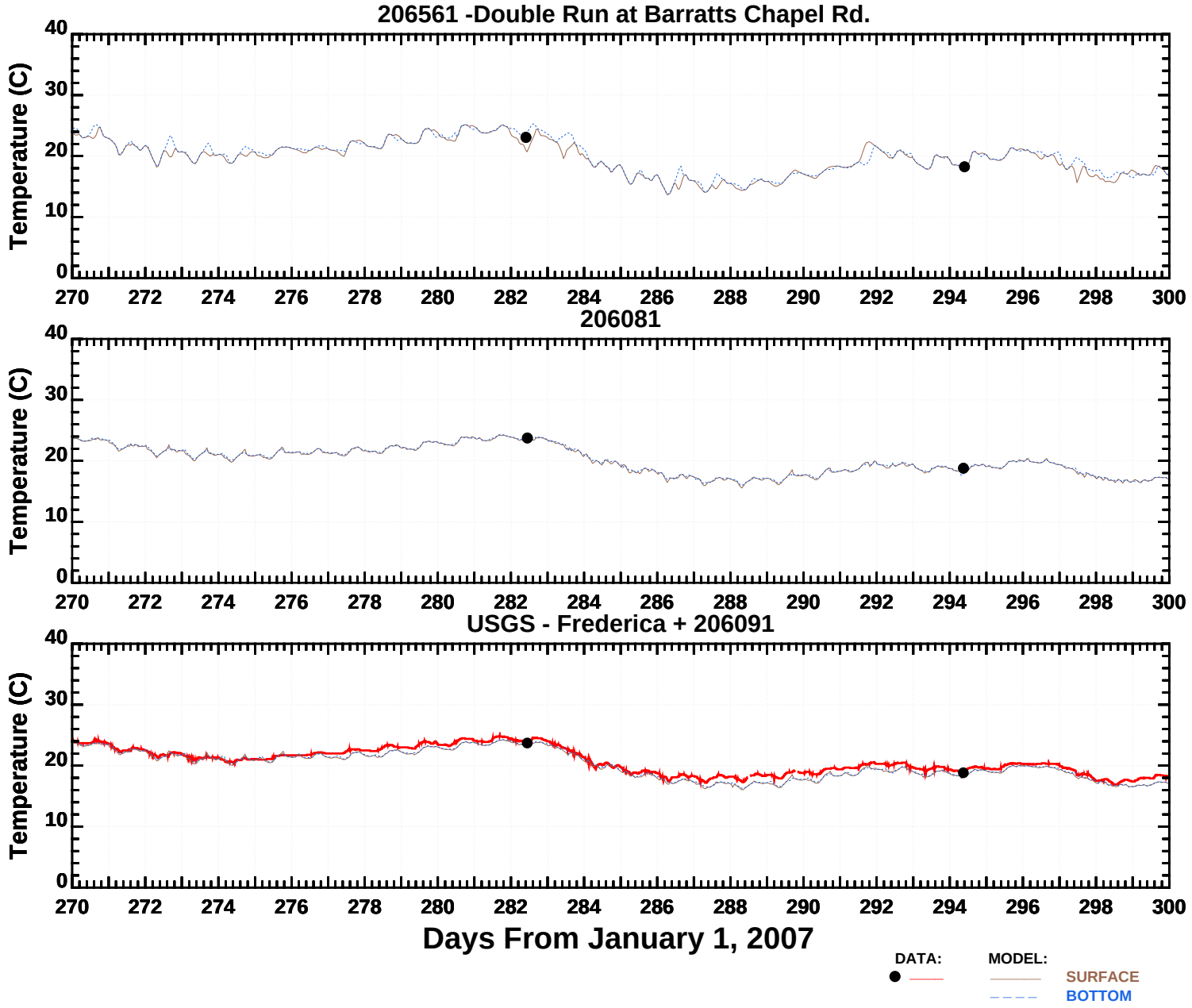
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 1 of 3
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13:31


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Temperature (C)
0
10
20
30
40
240
242
244
246
248
250
252
254
256
258
260
262
264
266
268
270
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



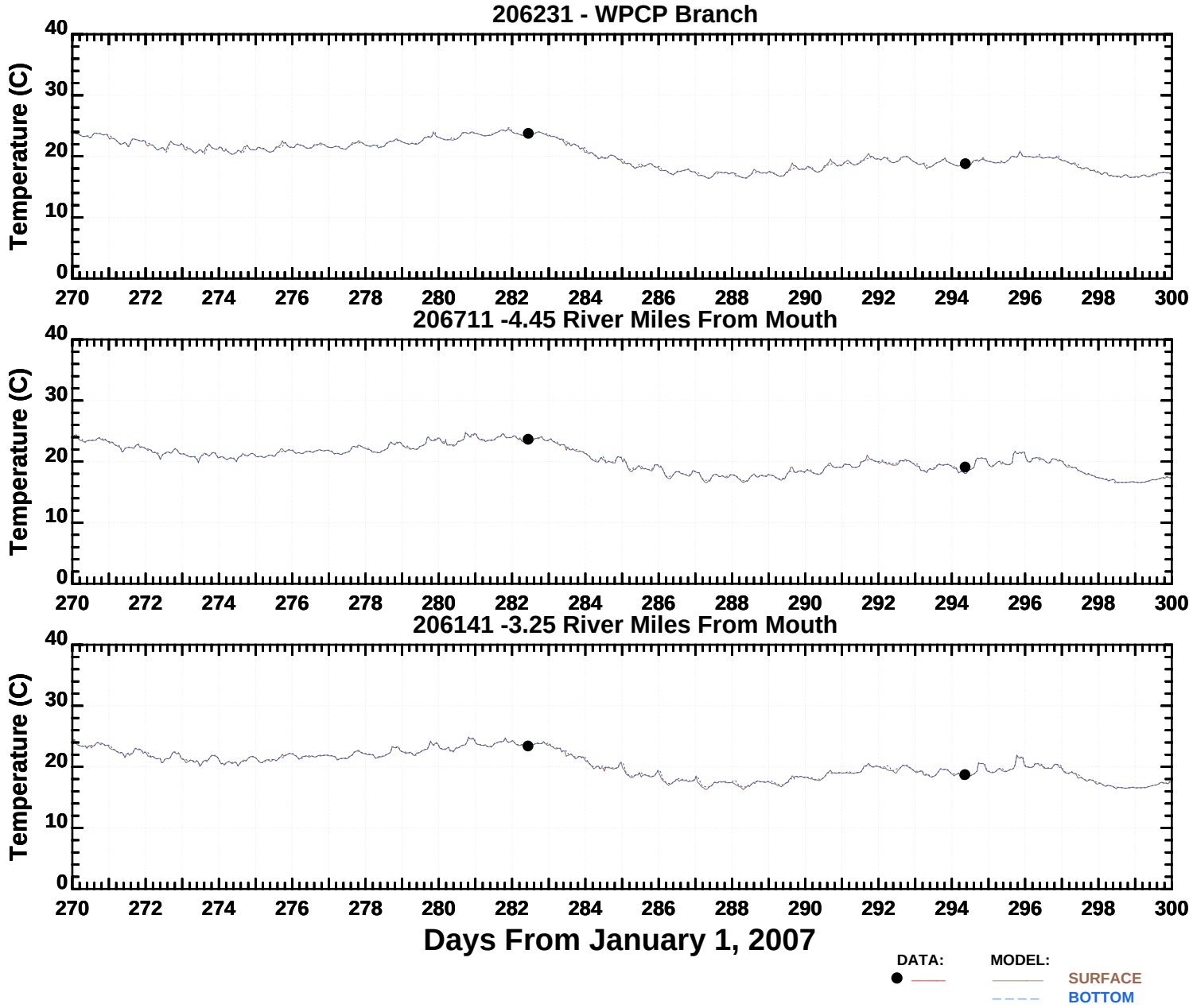
DATA: ● MODEL: SURFACE BOTTOM

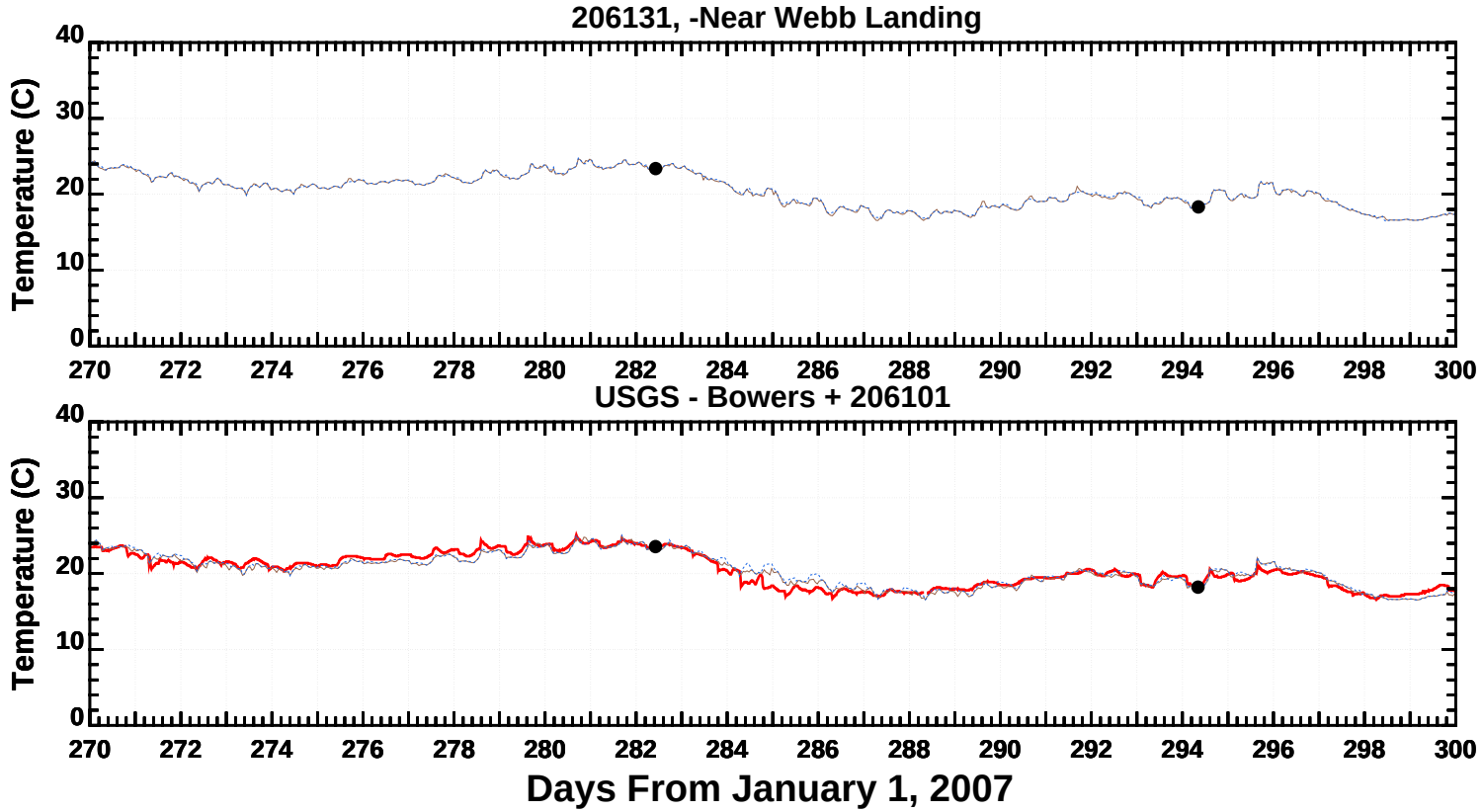


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13:38


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Temperature (C)
0
10
20
30
40
270
272
274
276
278
280
282
284
286
288
290
292
294
296
298
300
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

MODEL: ——— SURFACE

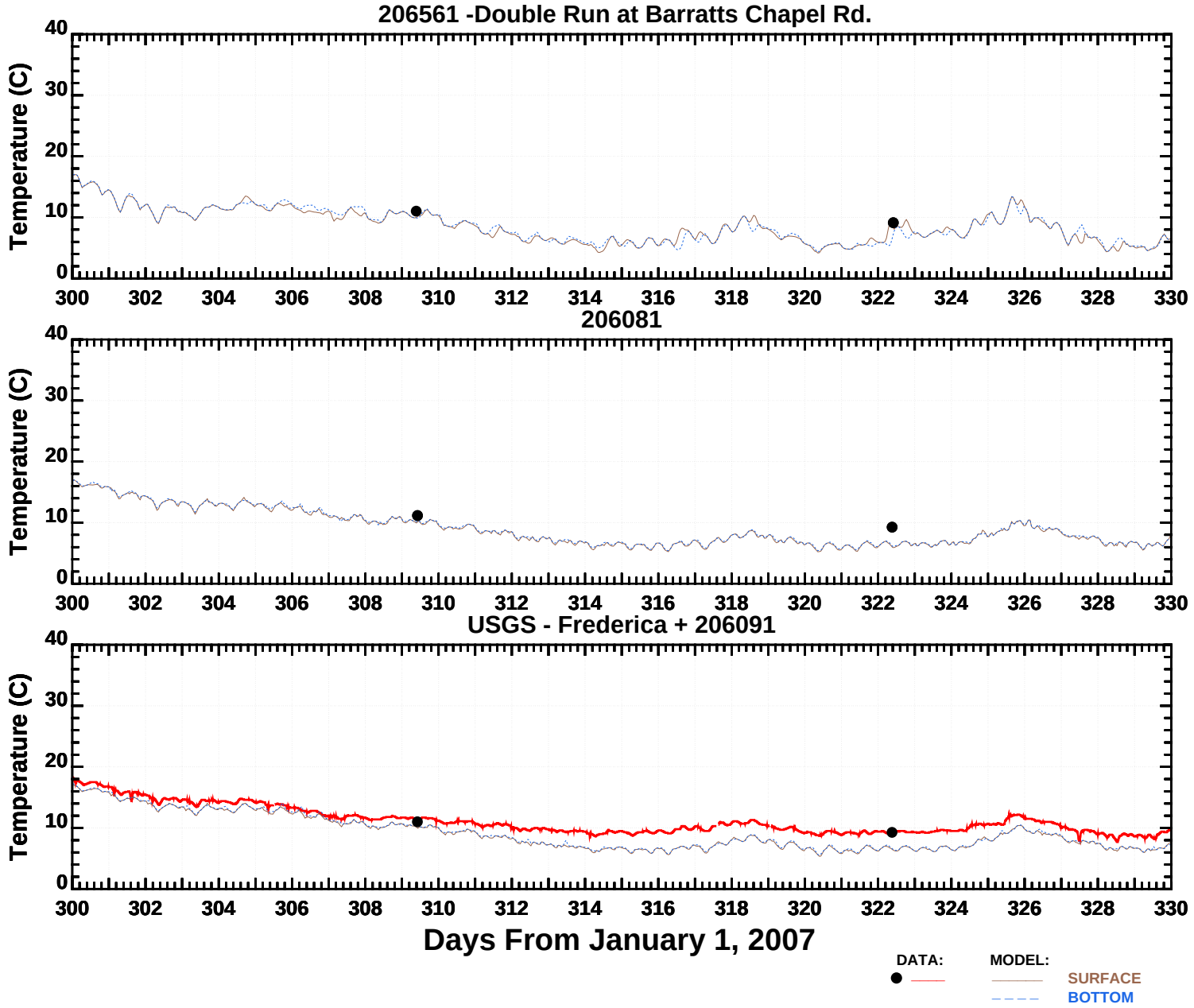
– – – – BOTTOM

DNREC Study

/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

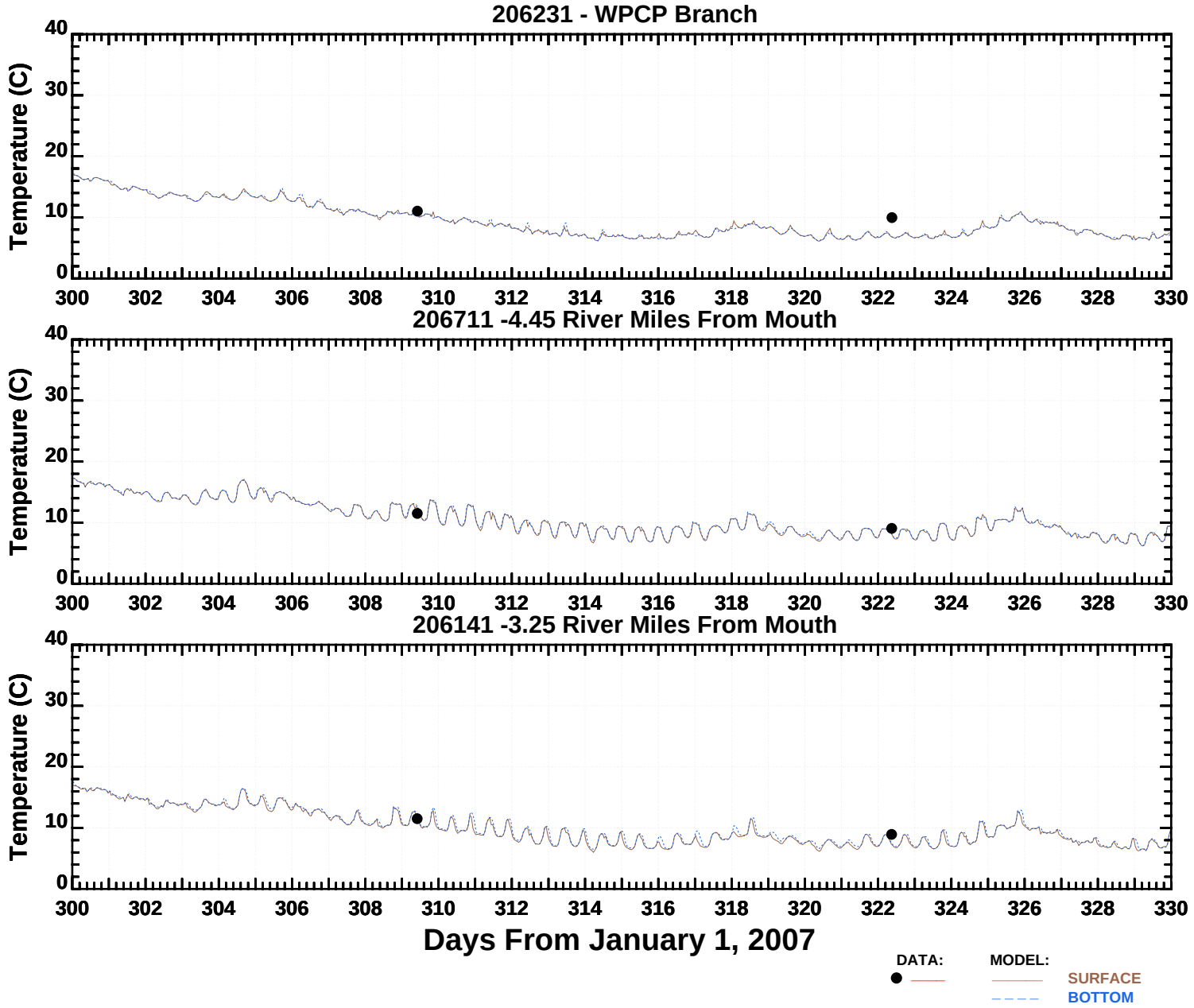
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 13:13:38



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 1 of 3
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

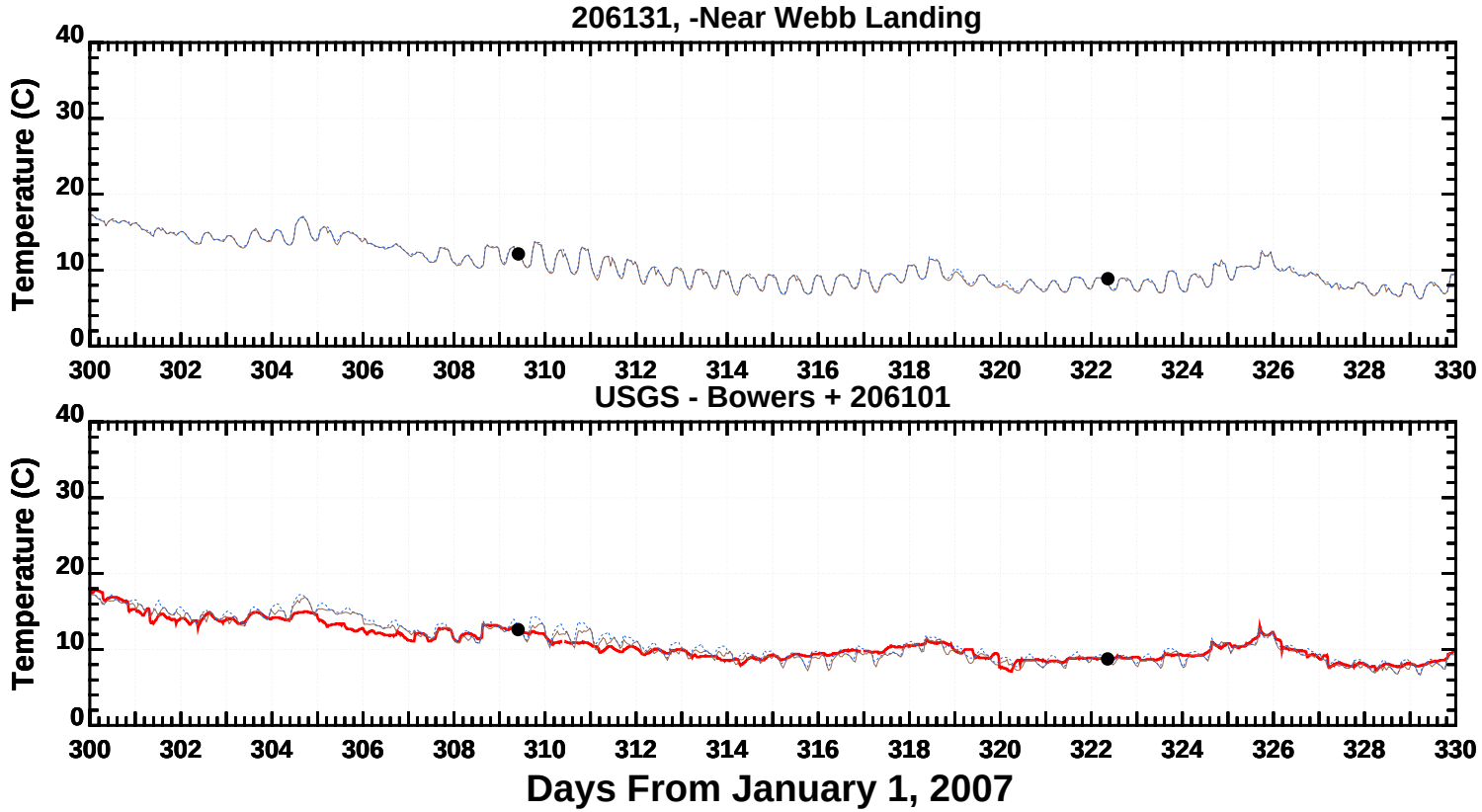
DATE: 1/22/2013 TIME: 13:13:46



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

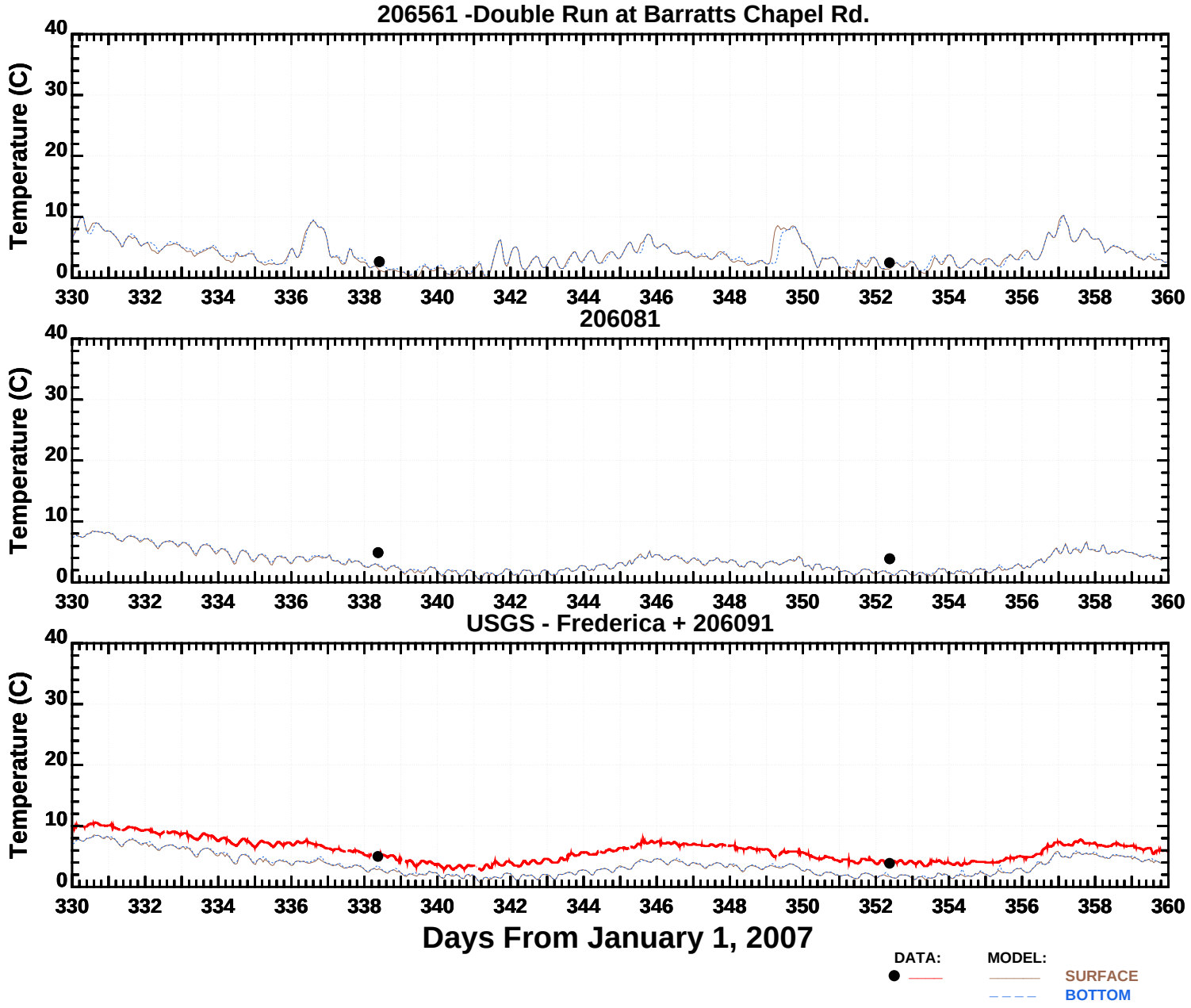
DATE: 1/22/2013 TIME: 13:13:46

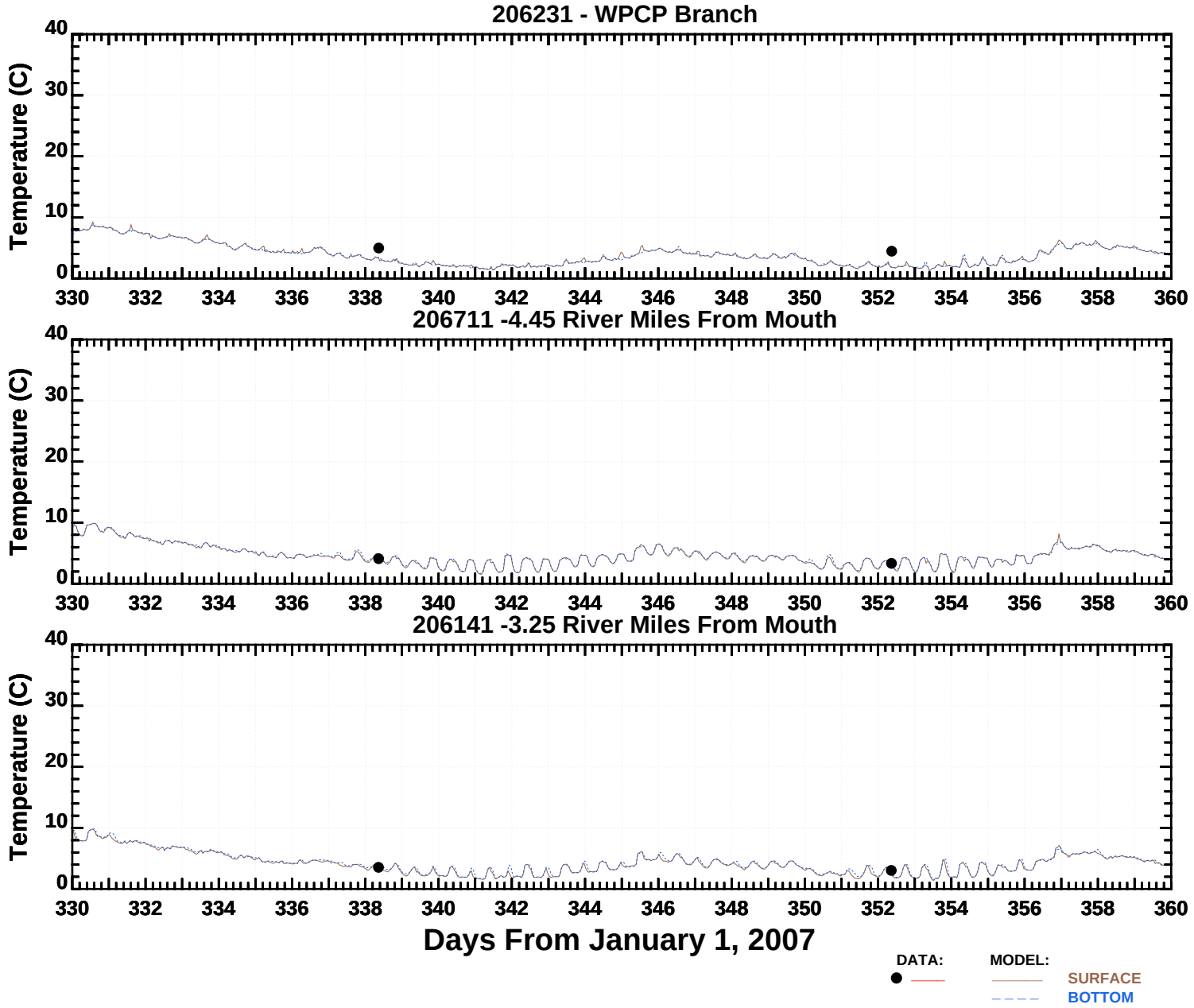


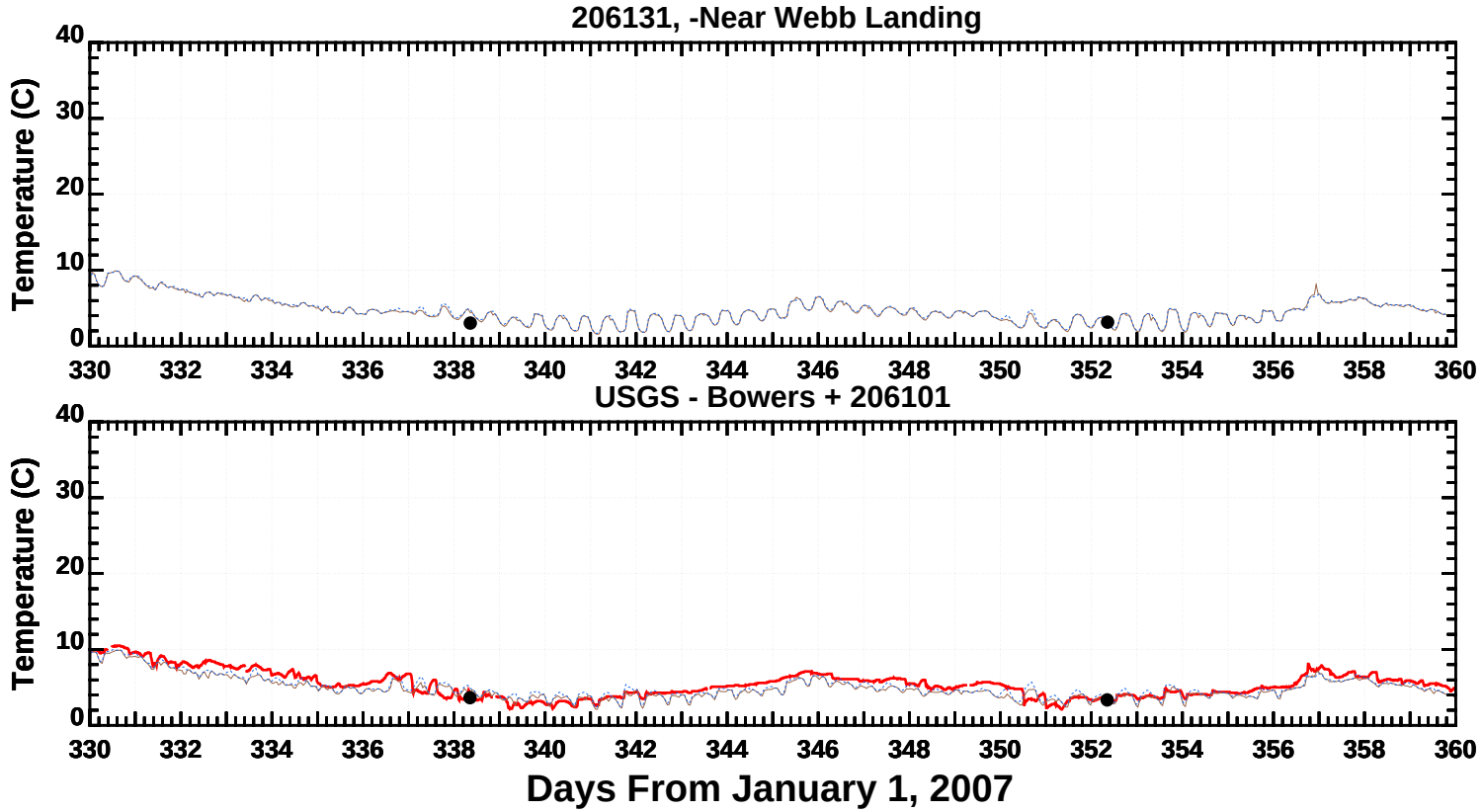
DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM


206561 -Double Run at Barratts Chapel Rd.
Temperature (C)
40
30
20
10
0
330
332
334
336
338
340
342
344
346
348
350
352
354
356
358
360
206081
USGS - Frederica + 206091
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM


206231 - WPCP Branch
Temperature (C)
0
10
20
30
40
330
332
334
336
338
340
342
344
346
348
350
352
354
356
358
360
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2007
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

MODEL: ——— SURFACE

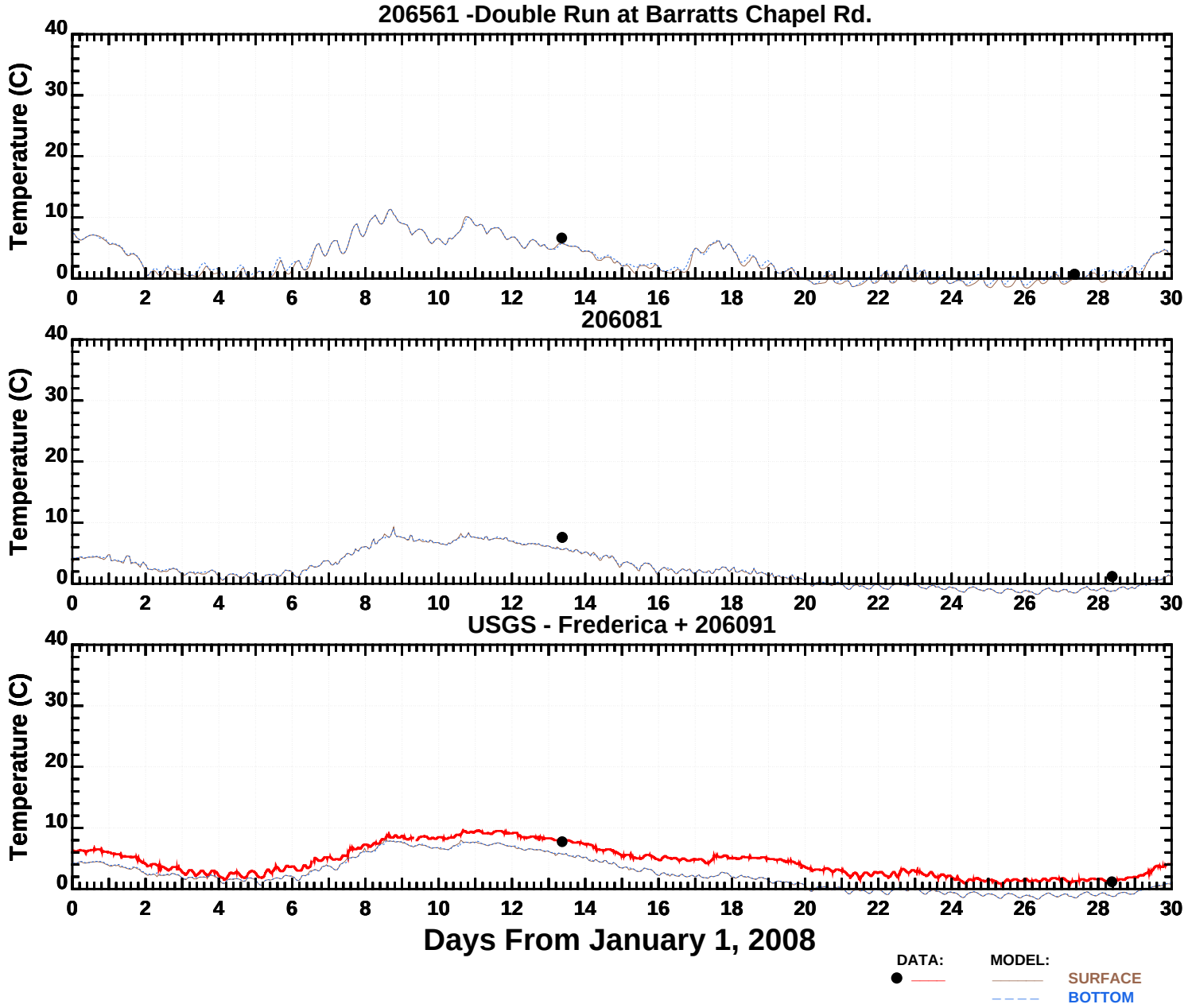
– – – – BOTTOM

DNREC Study

/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

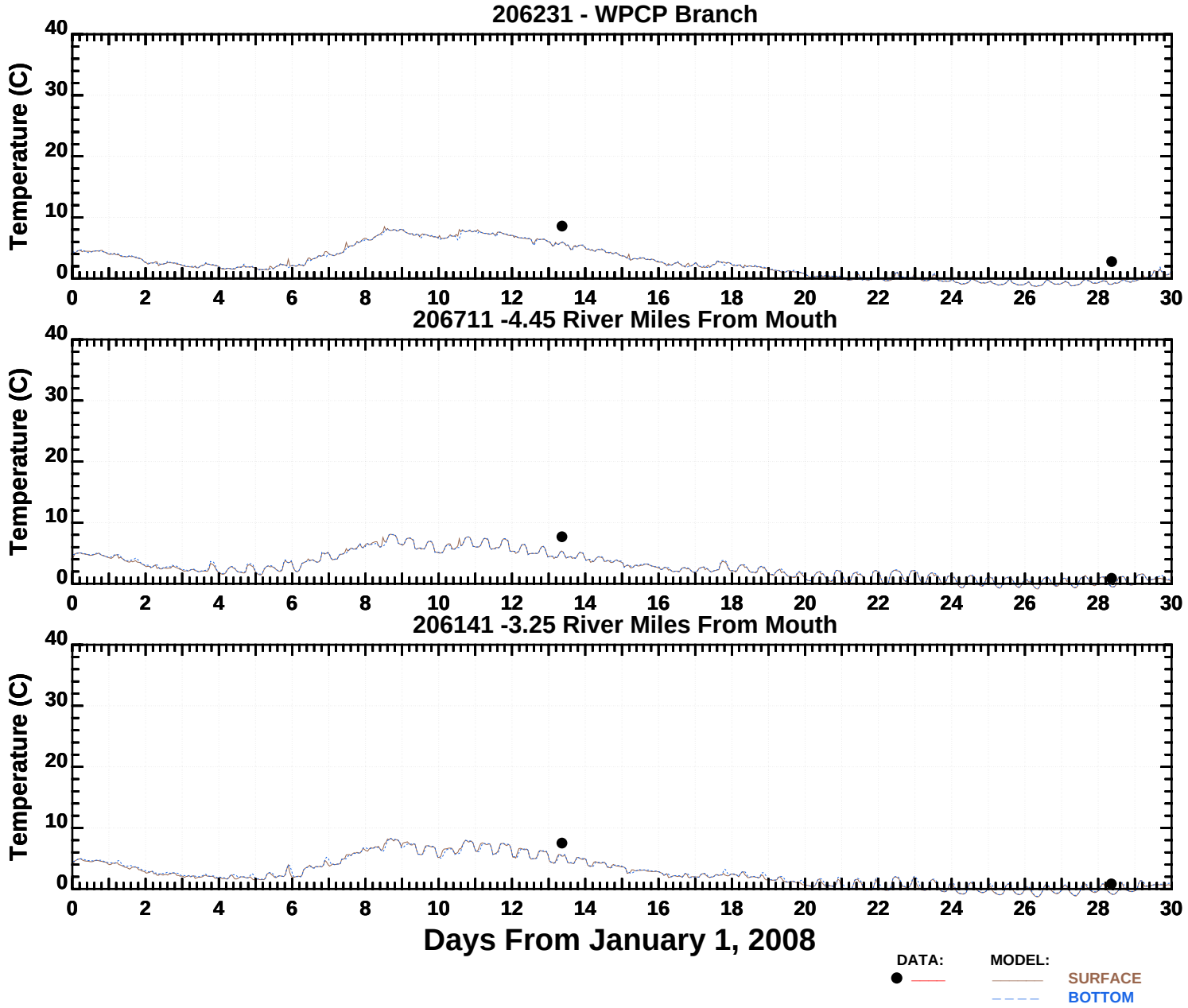
DATE: 1/22/2013 TIME: 13:13:53



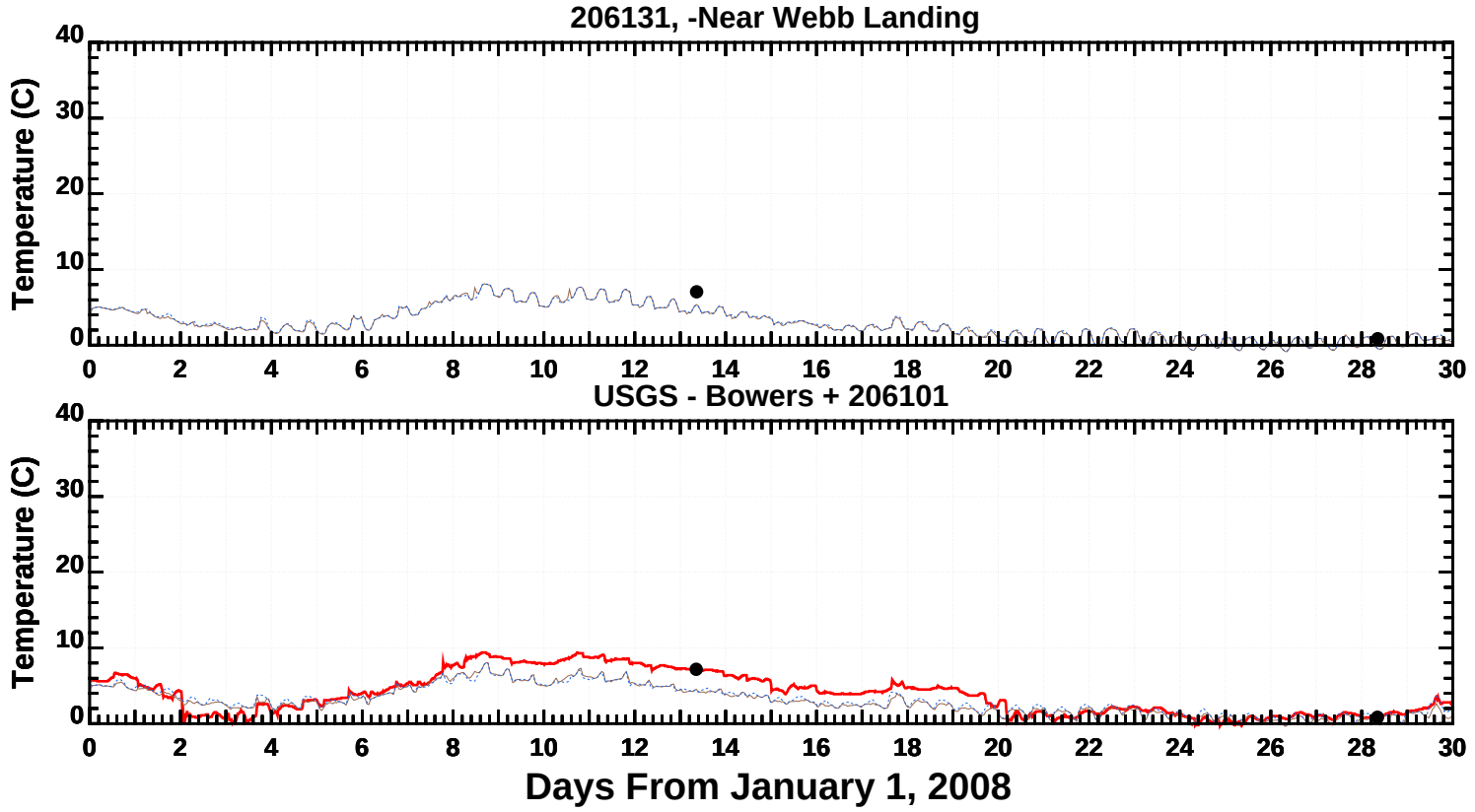
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:15:37



DATE: 1/22/2013 TIME: 13:15:37



DATA: ● ——

MODEL: ——— SURFACE

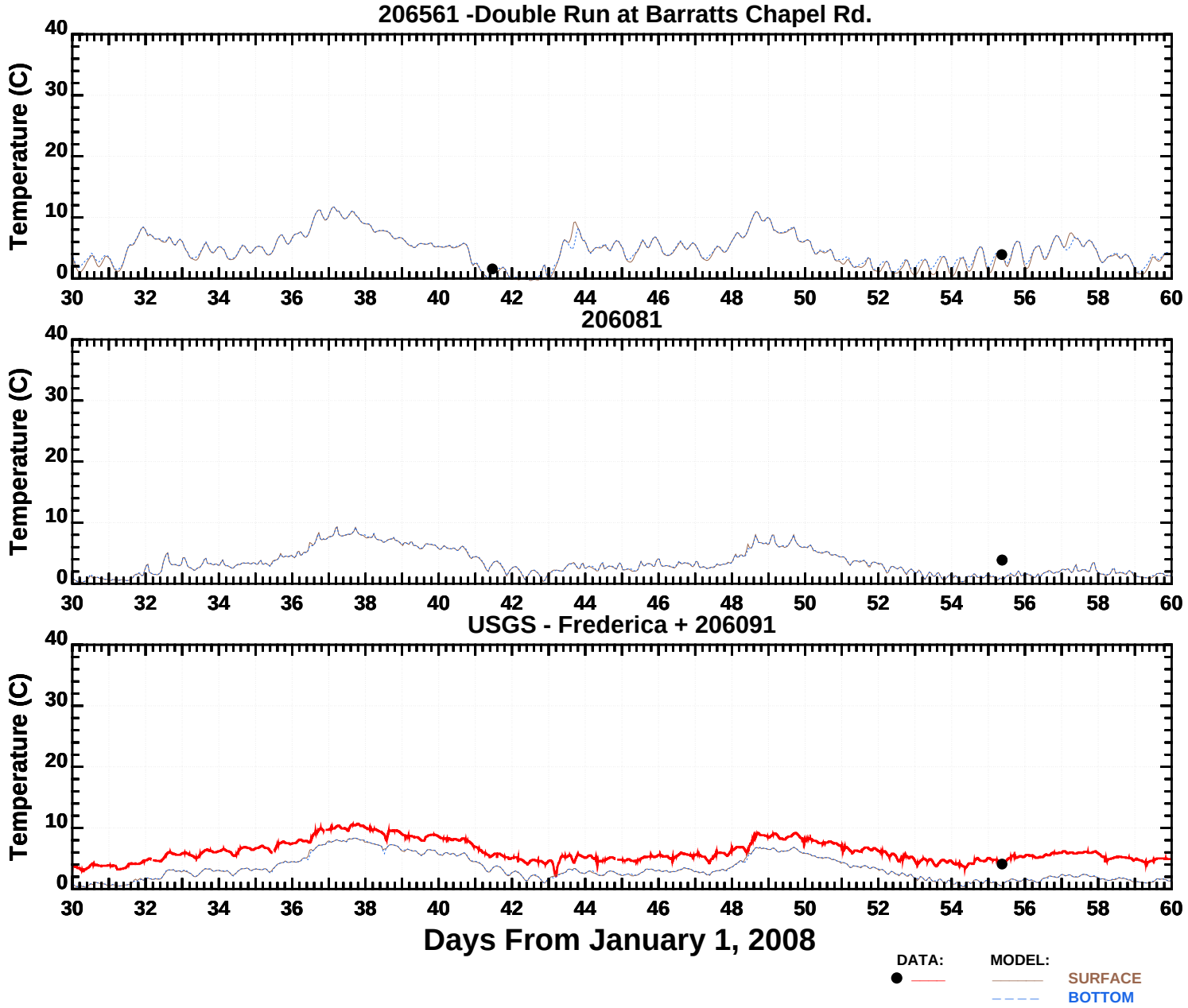
– – – – BOTTOM

DNREC Study

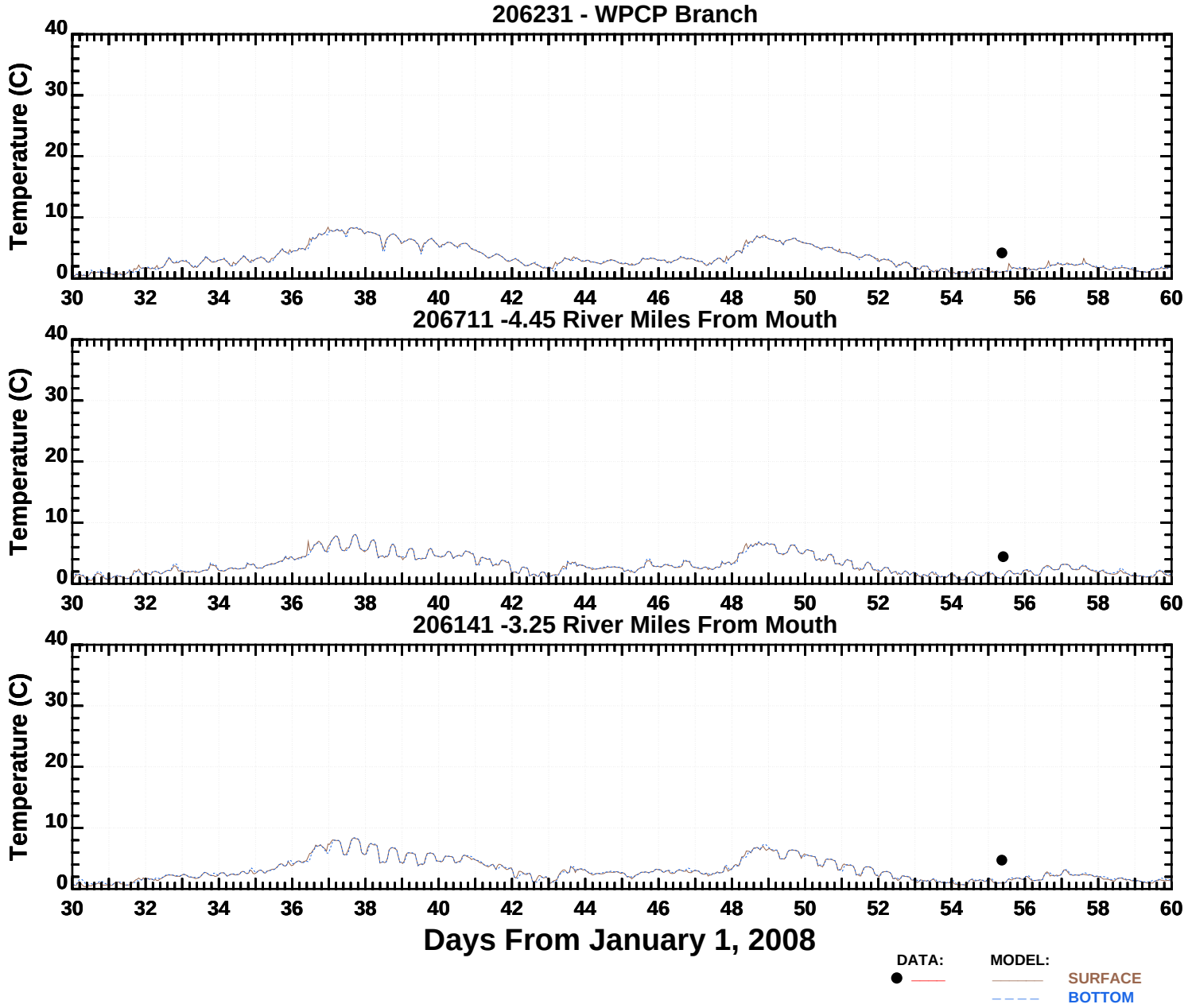
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

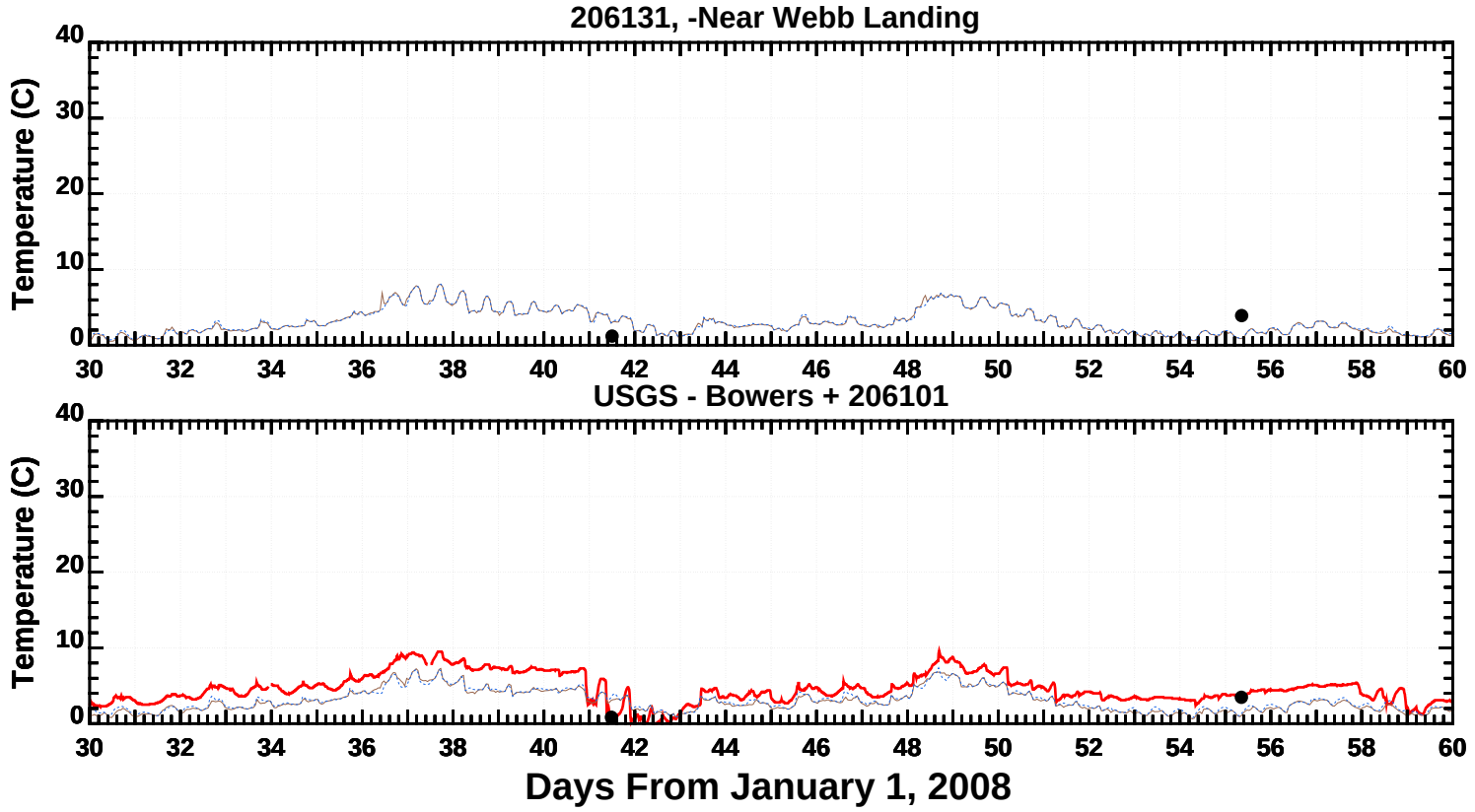
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:15:37



DATE: 1/22/2013 TIME: 13:15:44


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Temperature (C)
0
10
20
30
40
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

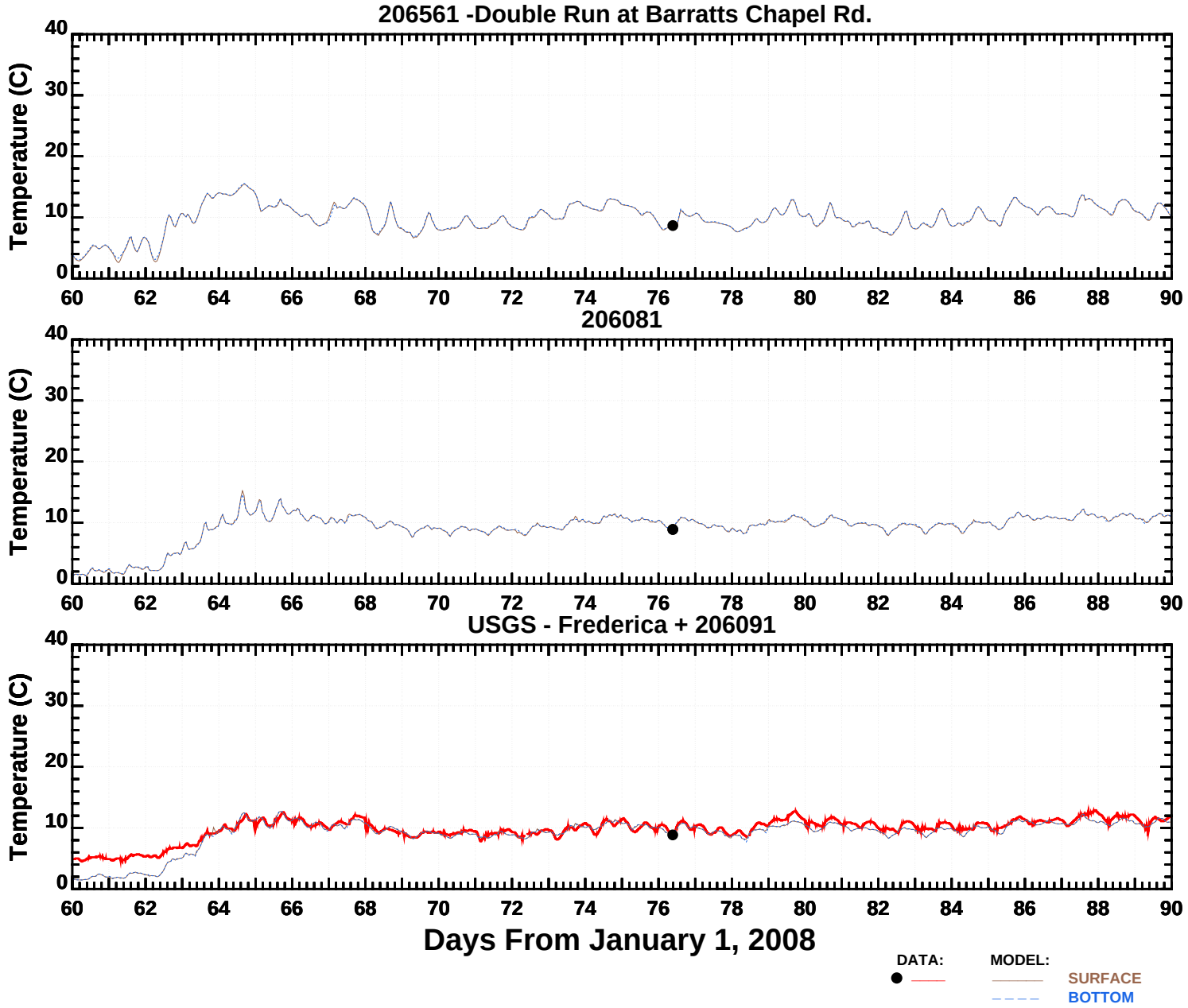


DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM

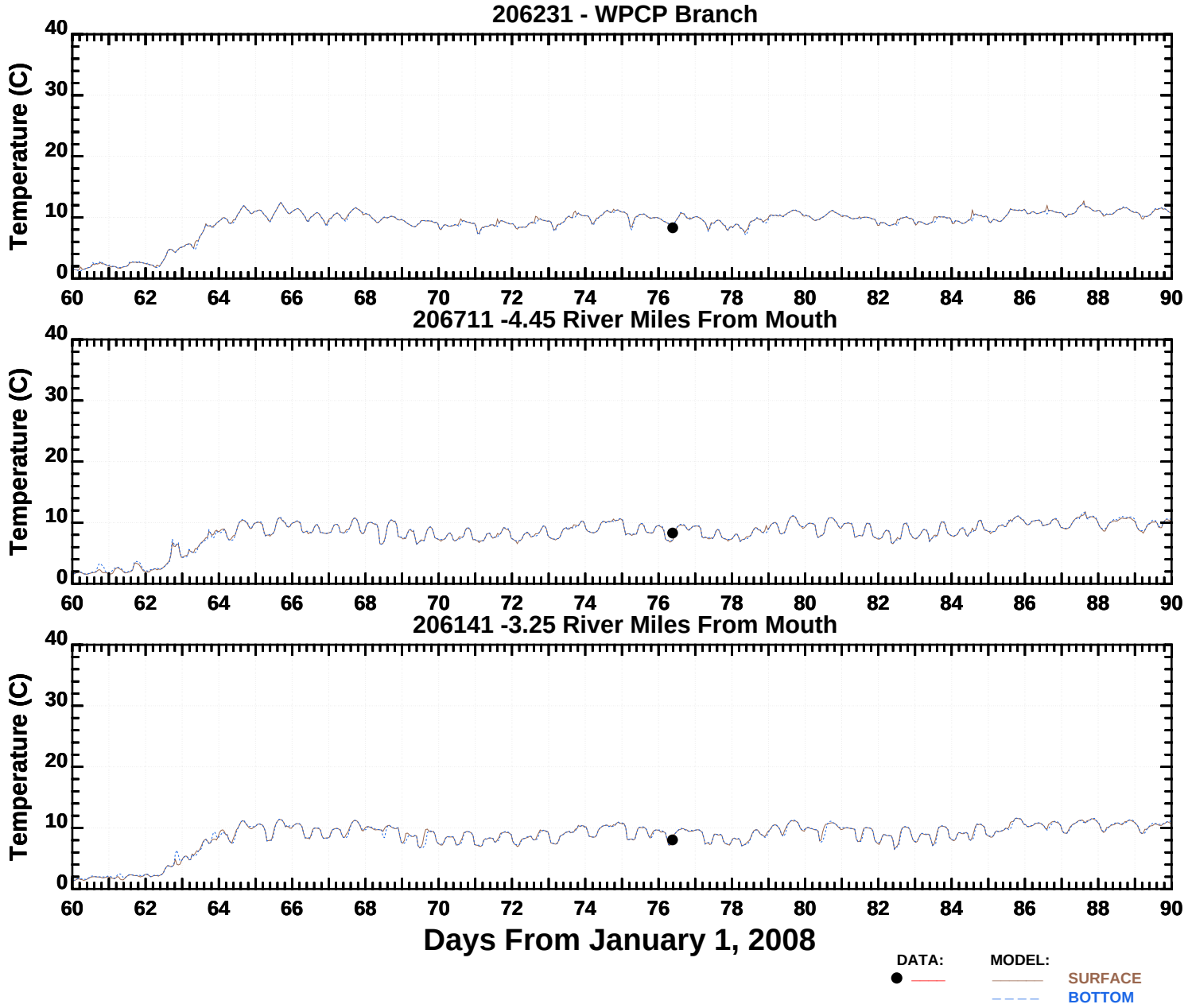
DATE: 1/22/2013 TIME: 13:15:44

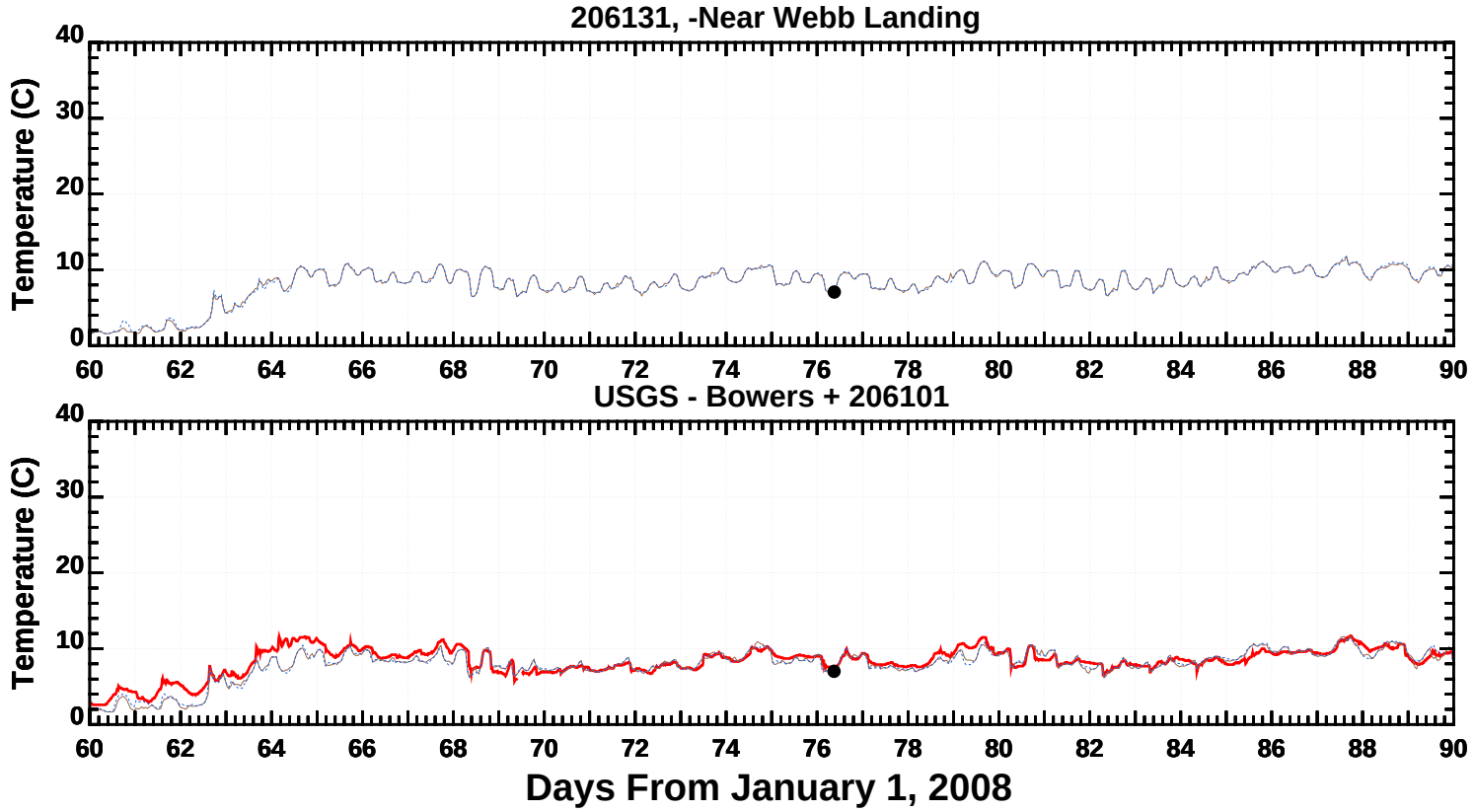


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

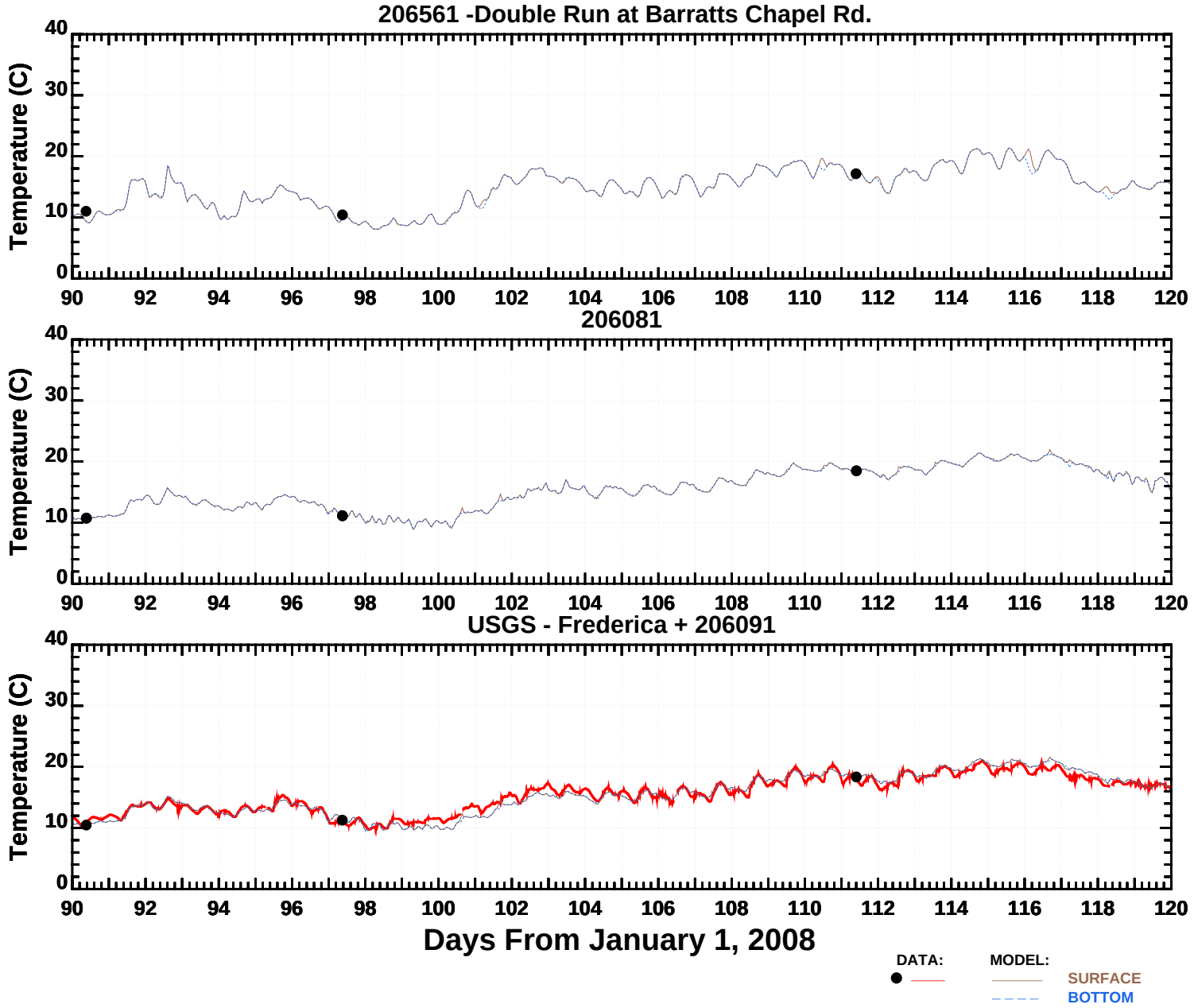
DATE: 1/22/2013 TIME: 13:15:52


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● MODEL: SURFACE BOTTOM

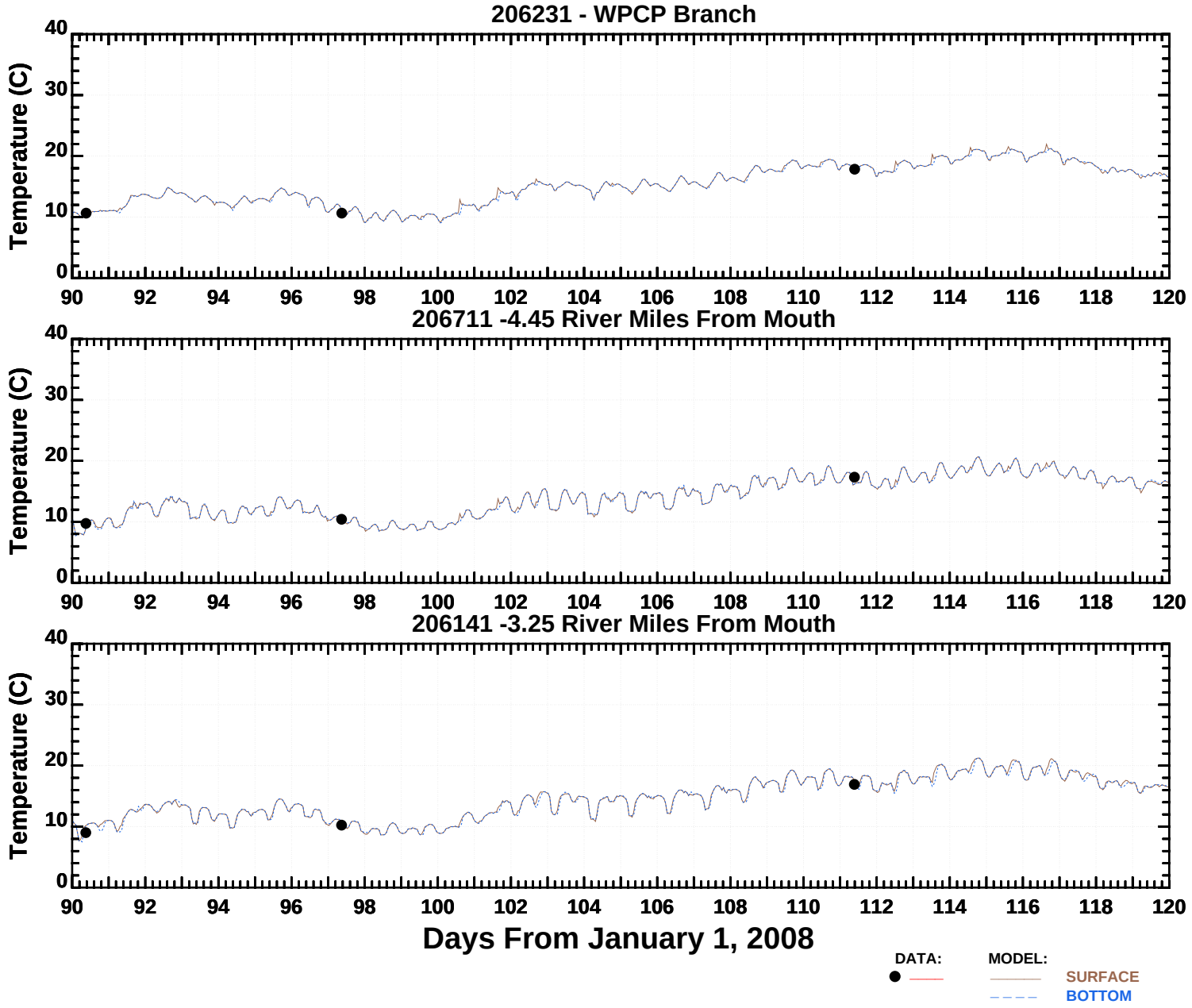
DATE: 1/22/2013 TIME: 13:15:52

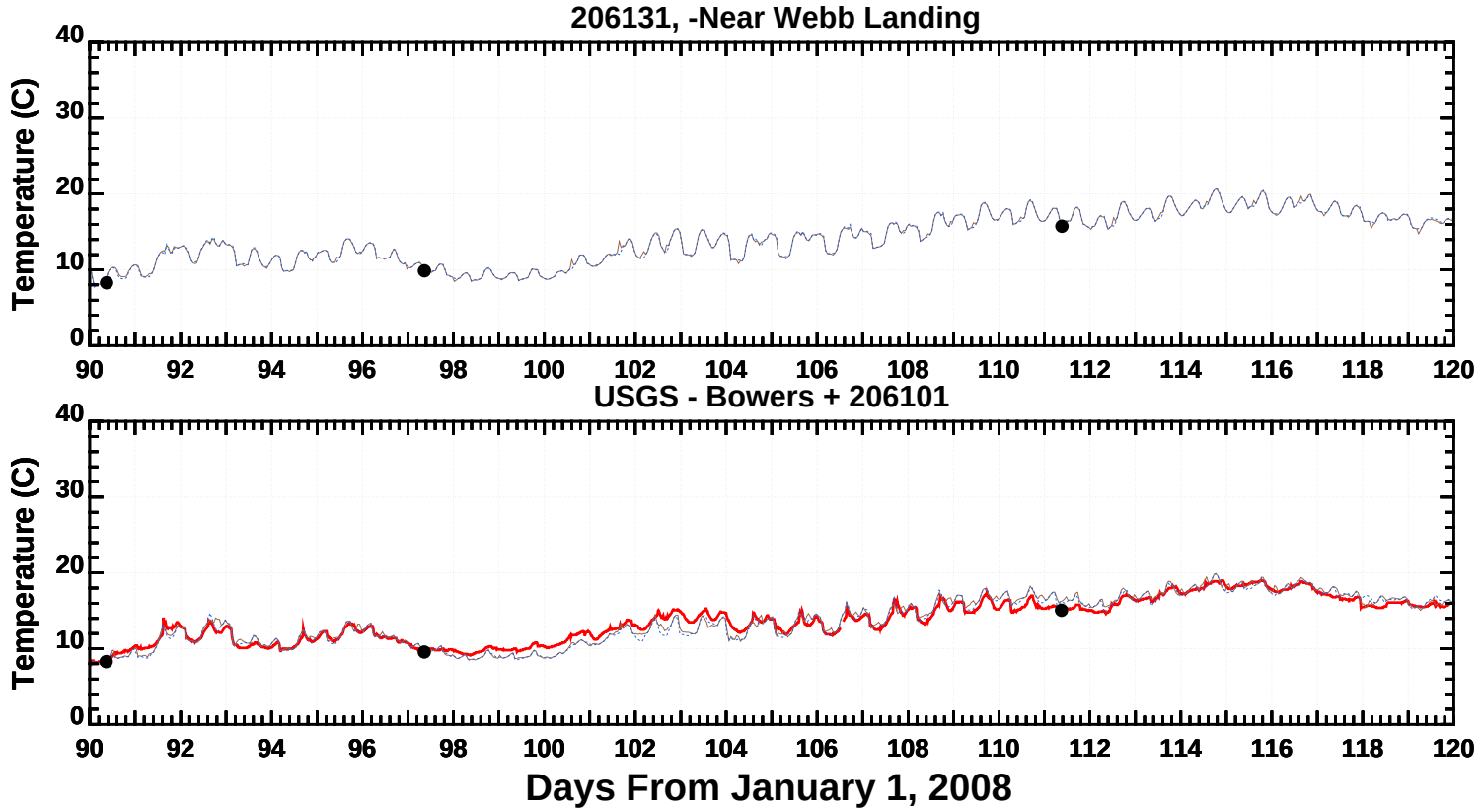


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

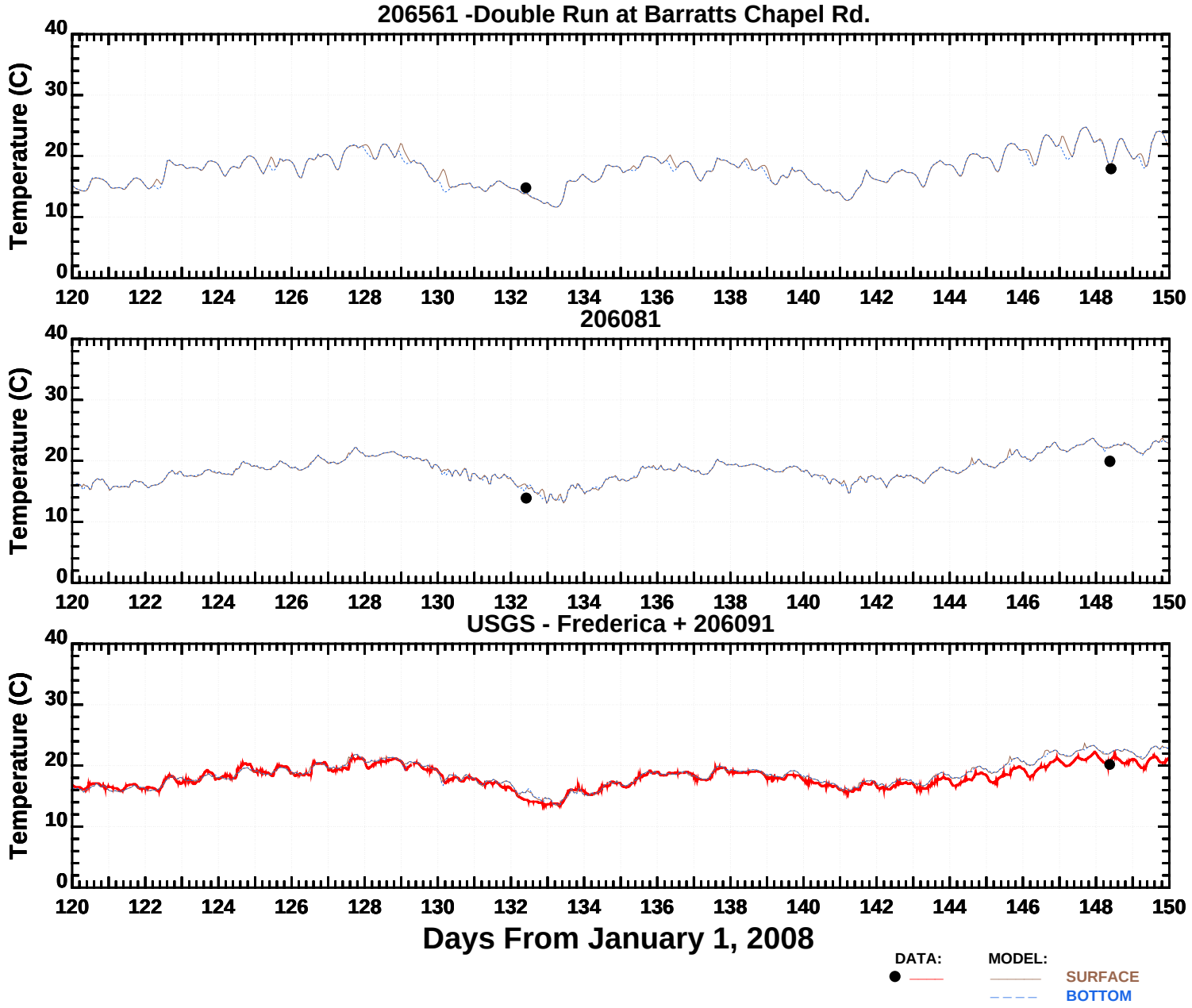
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:15:59


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



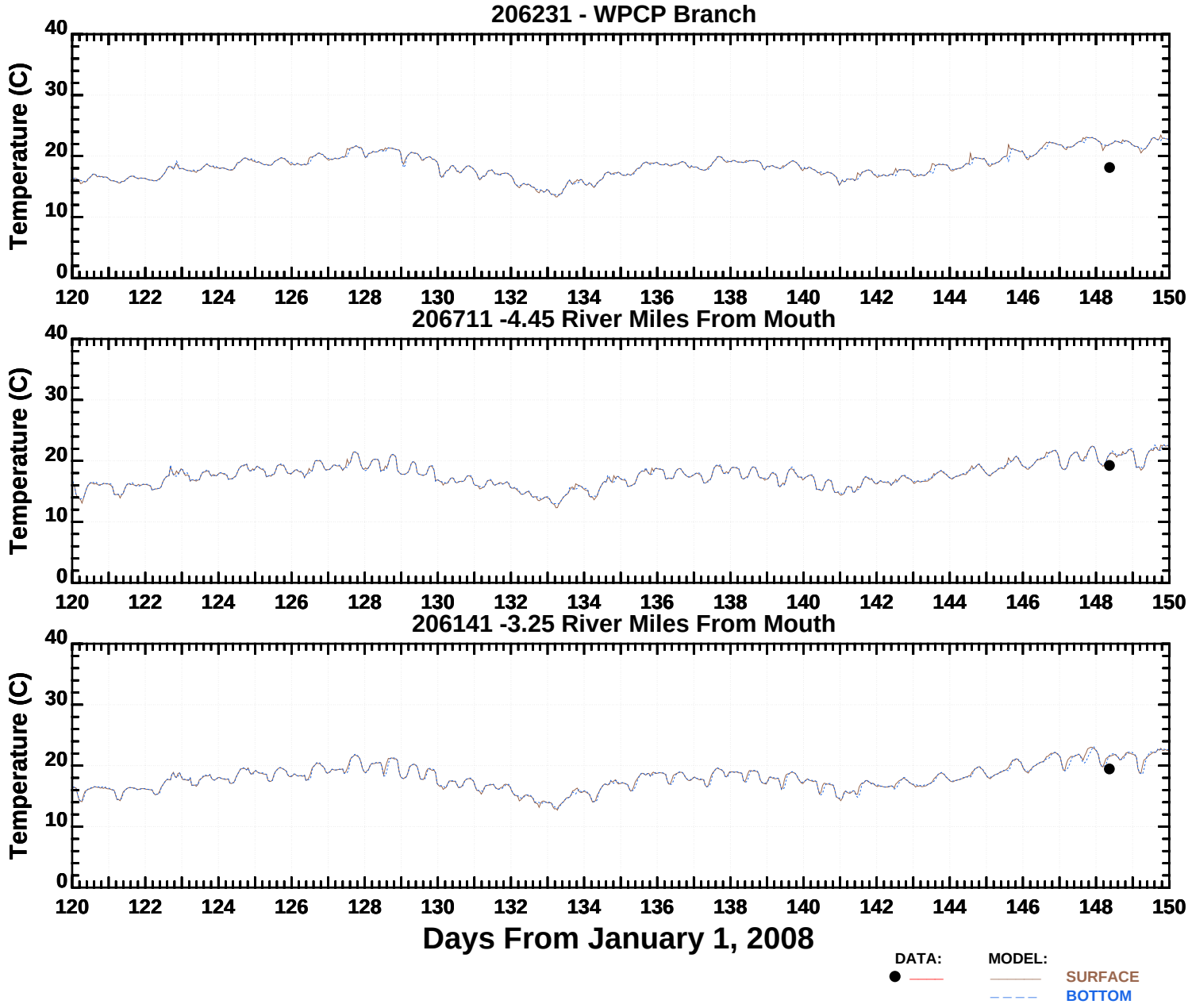
DATA: ● MODEL: SURFACE BOTTOM

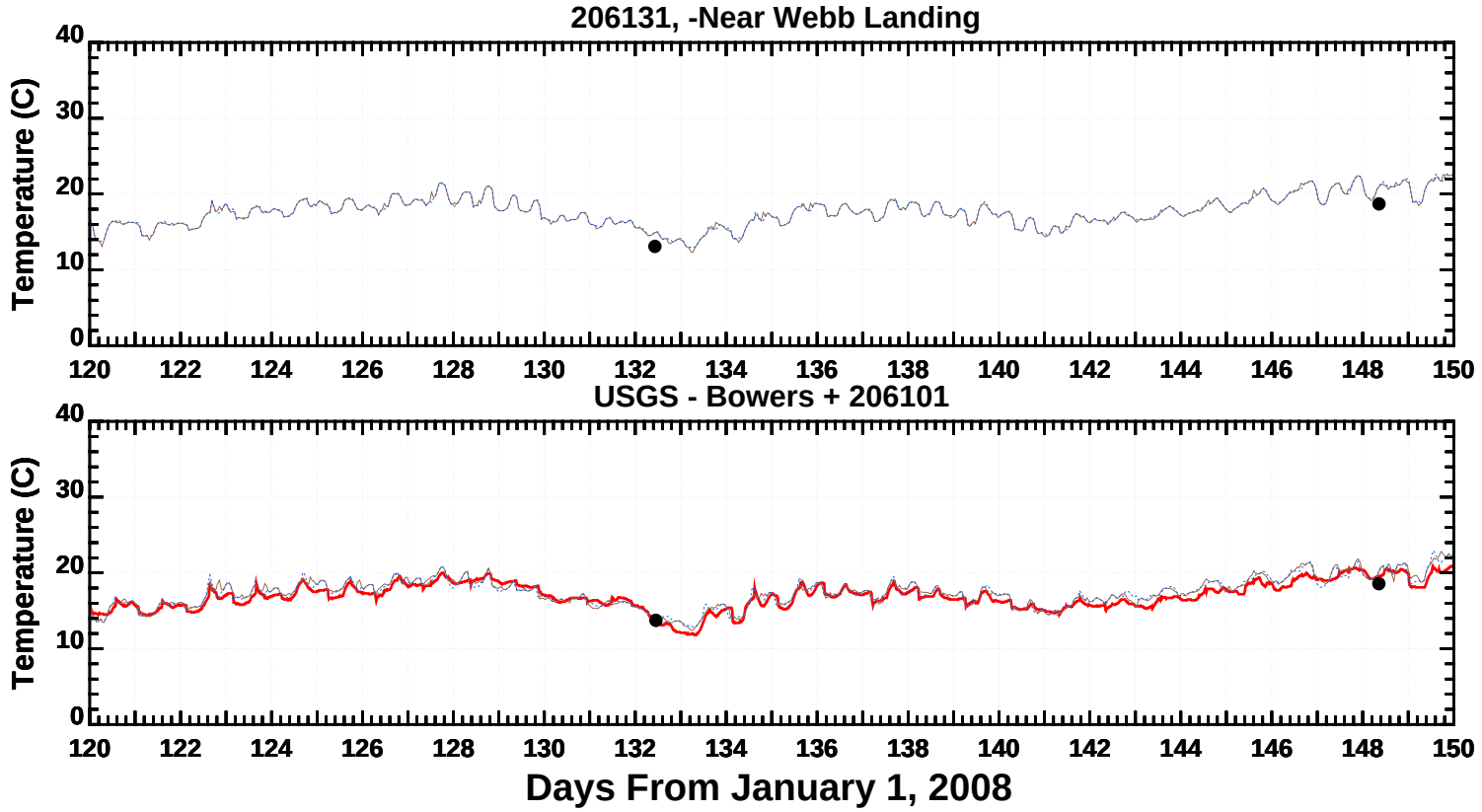


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:16: 7

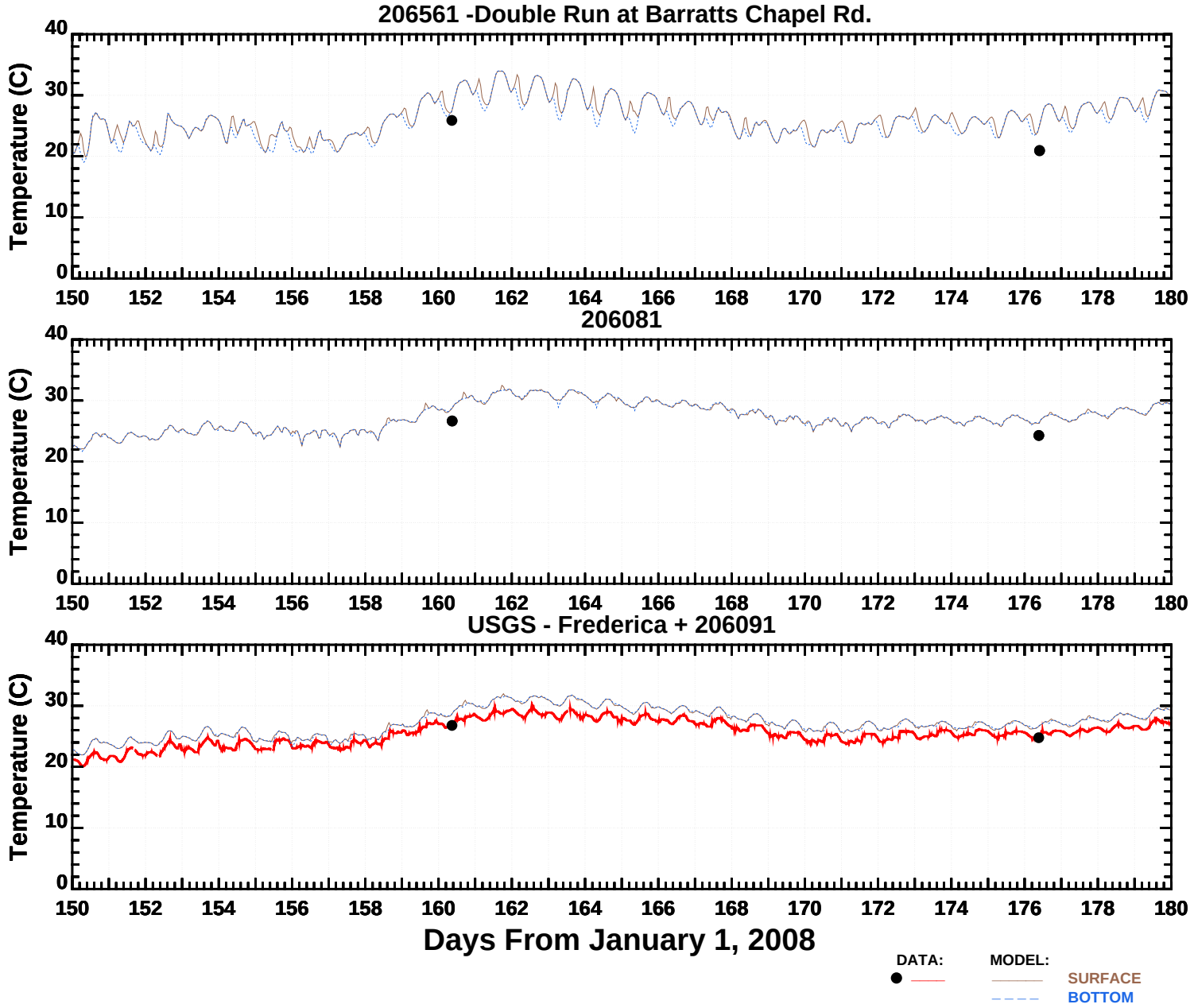

206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



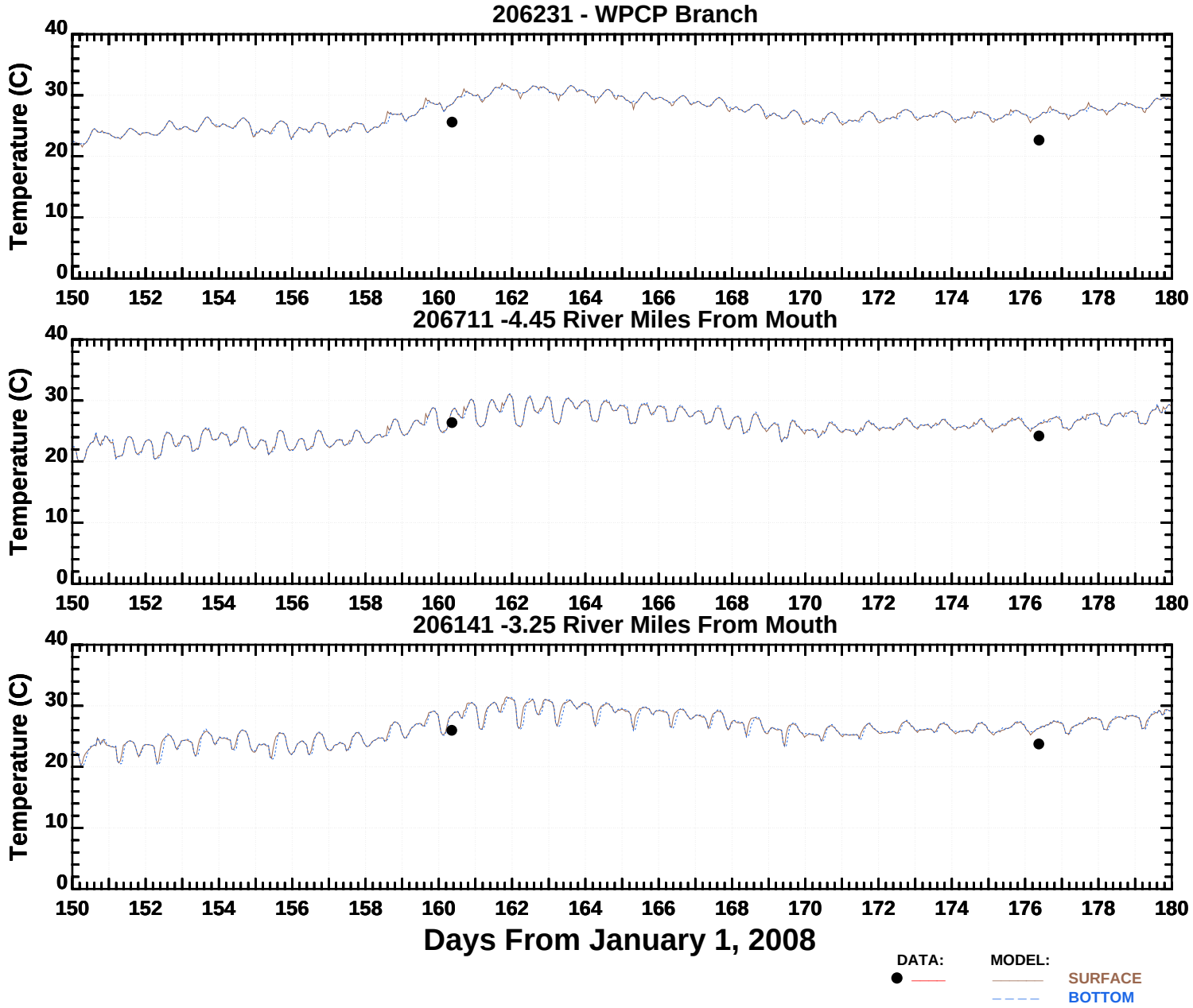
DATA: ● MODEL: SURFACE BOTTOM

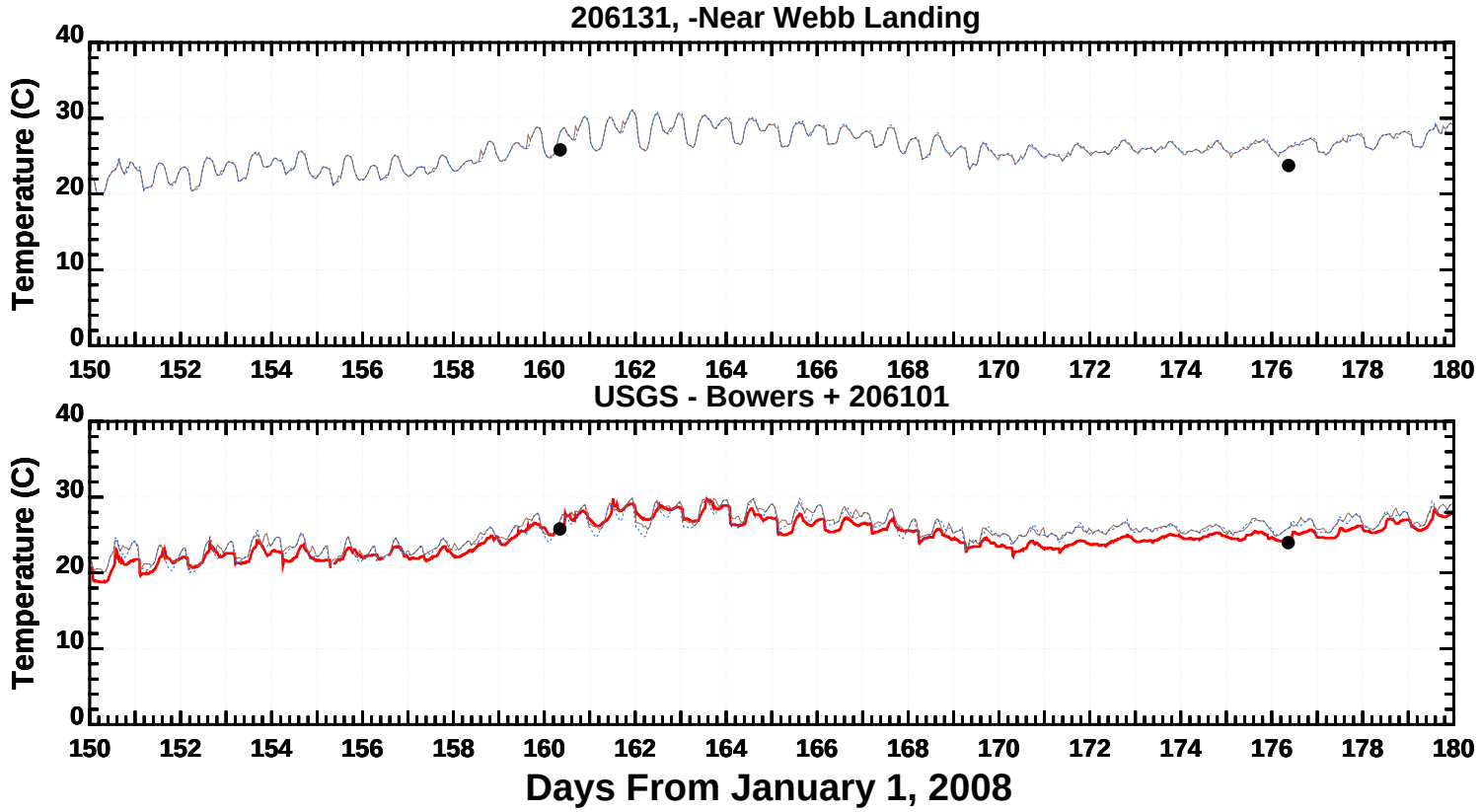
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 3 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:16: 7



DATE: 1/22/2013 TIME: 13:16:14

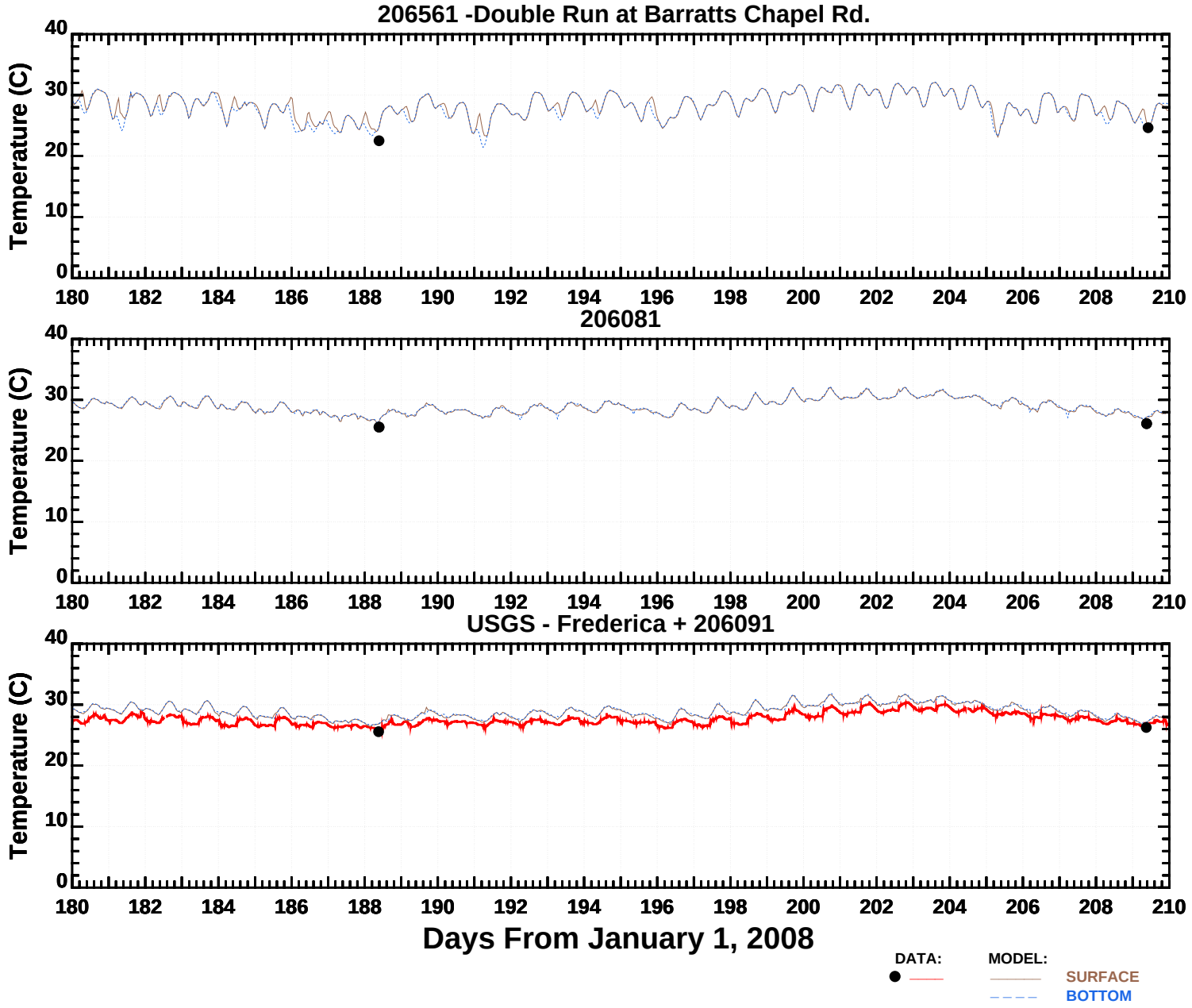

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Temperature (C)
0
10
20
30
40
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



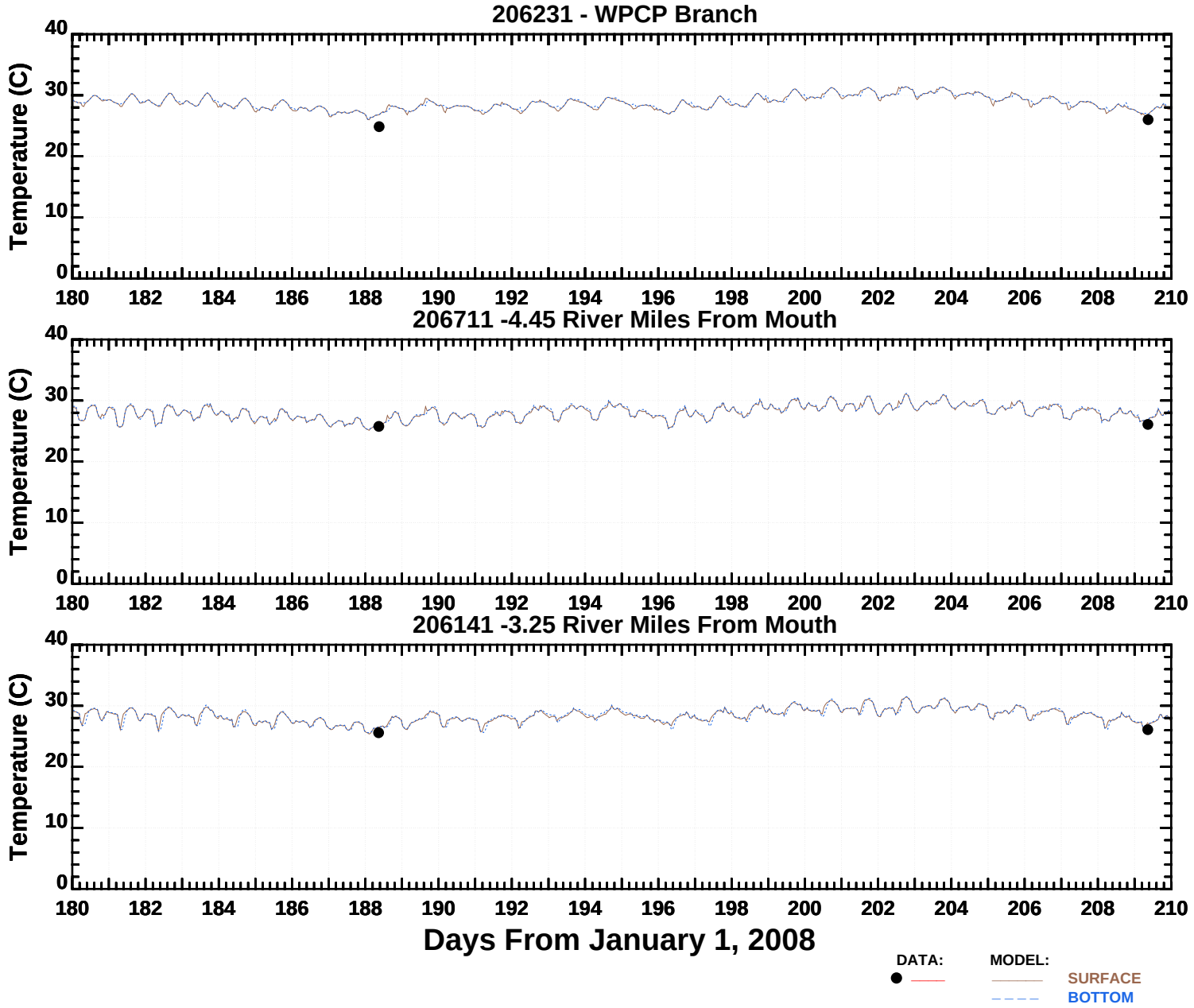
DATA: ● ——

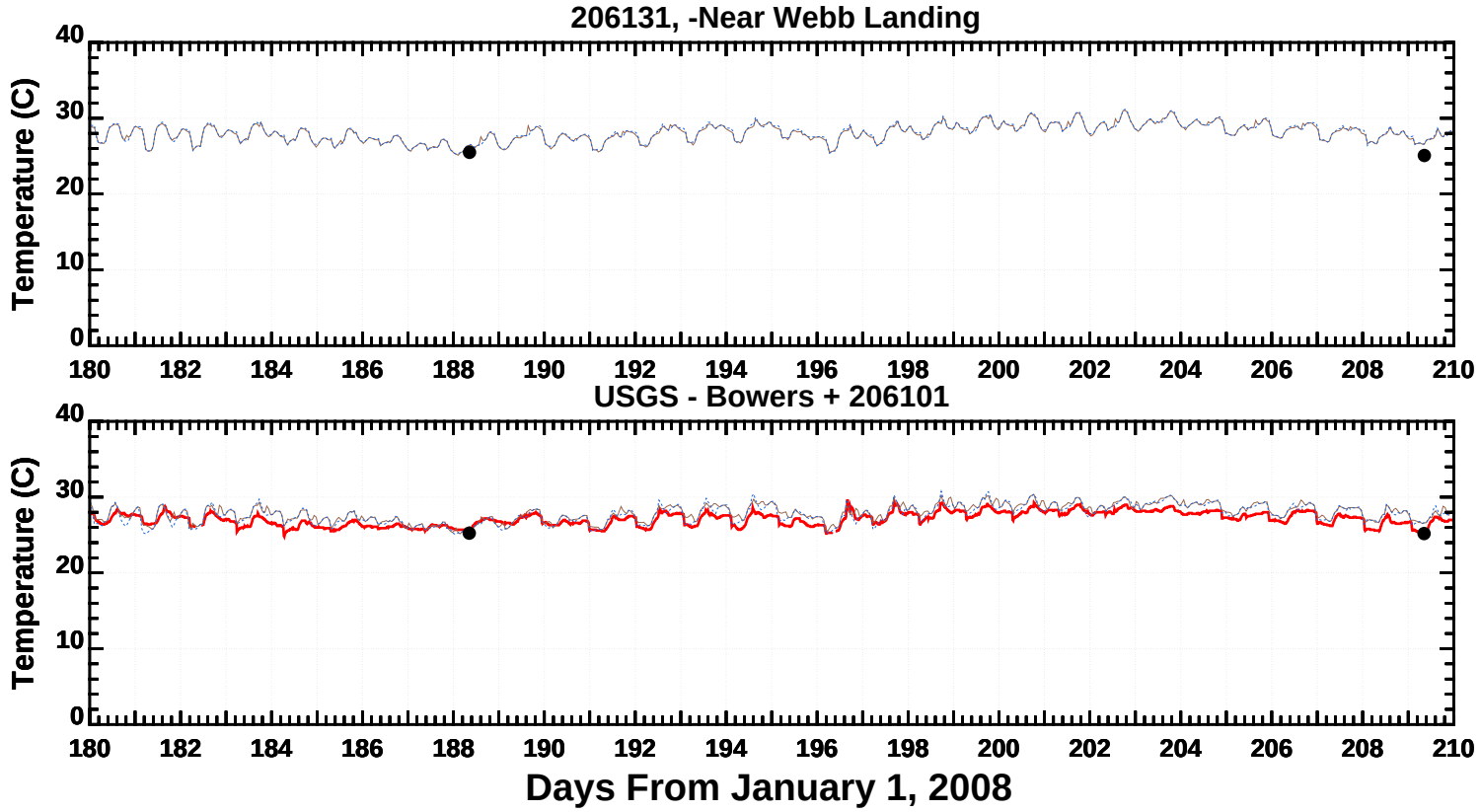
MODEL: ——— SURFACE

– – – – BOTTOM



DATE: 1/22/2013 TIME: 13:16:21

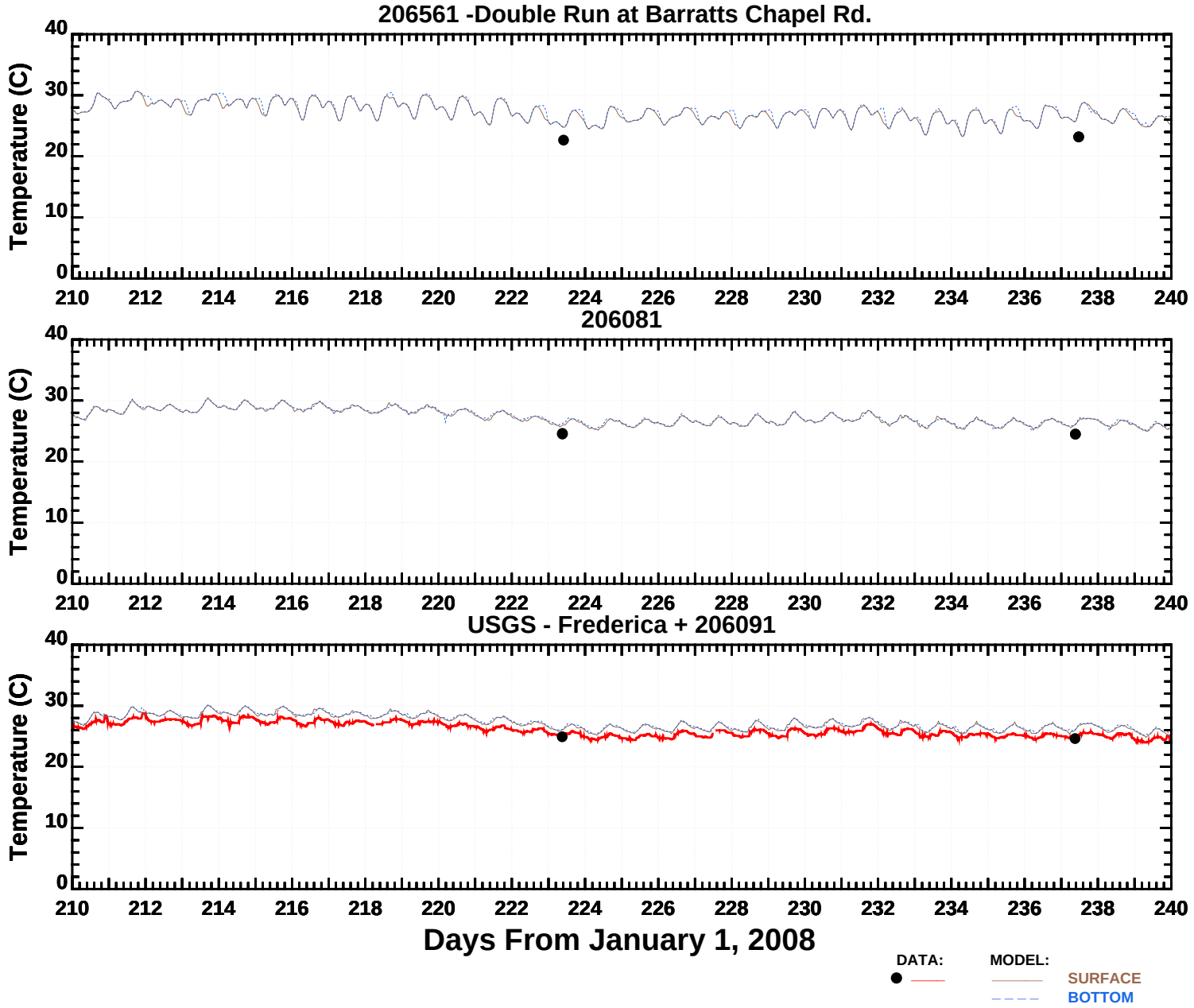

206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Temperature (C)
0
10
20
30
40
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



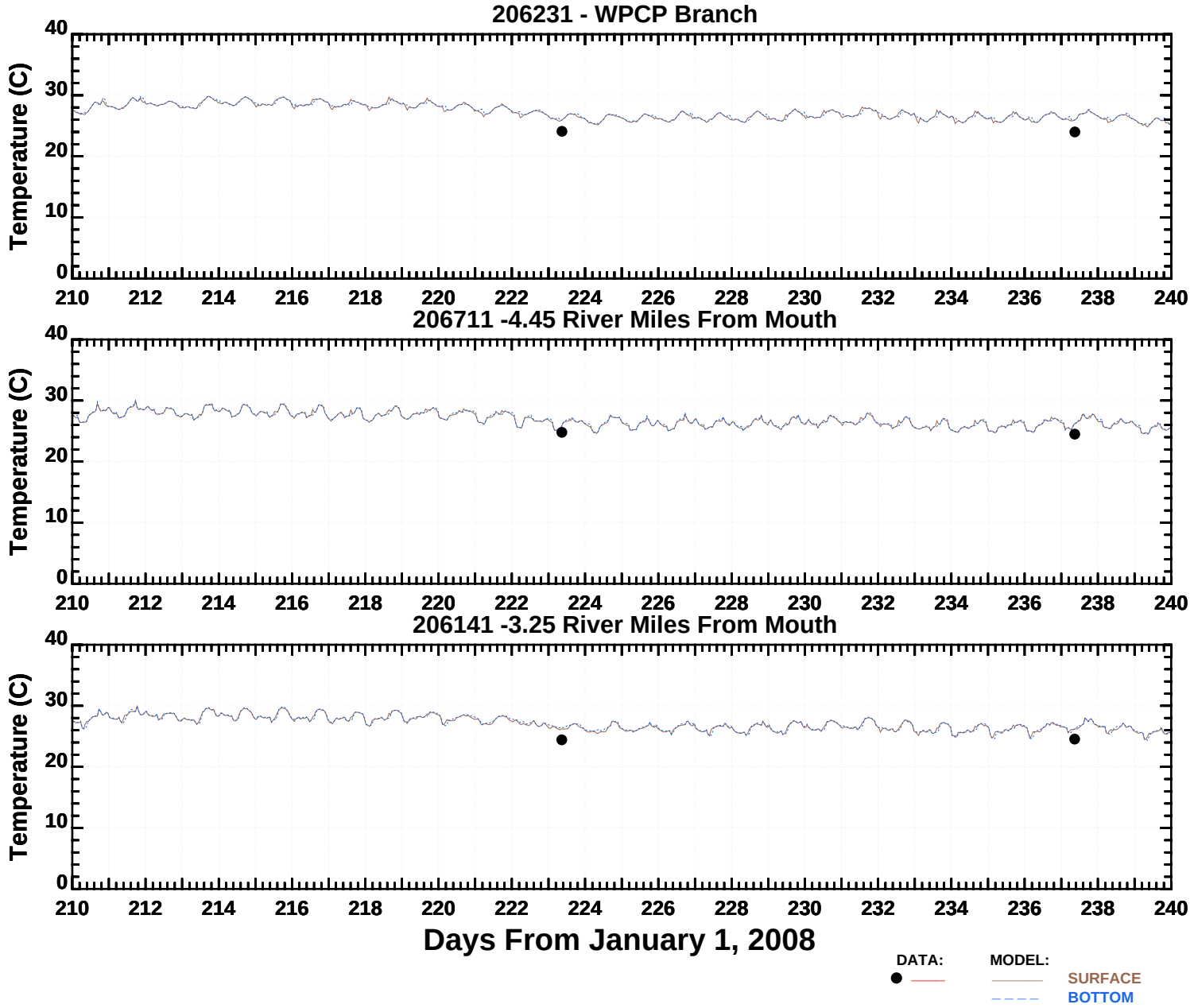
DATA: ● ——

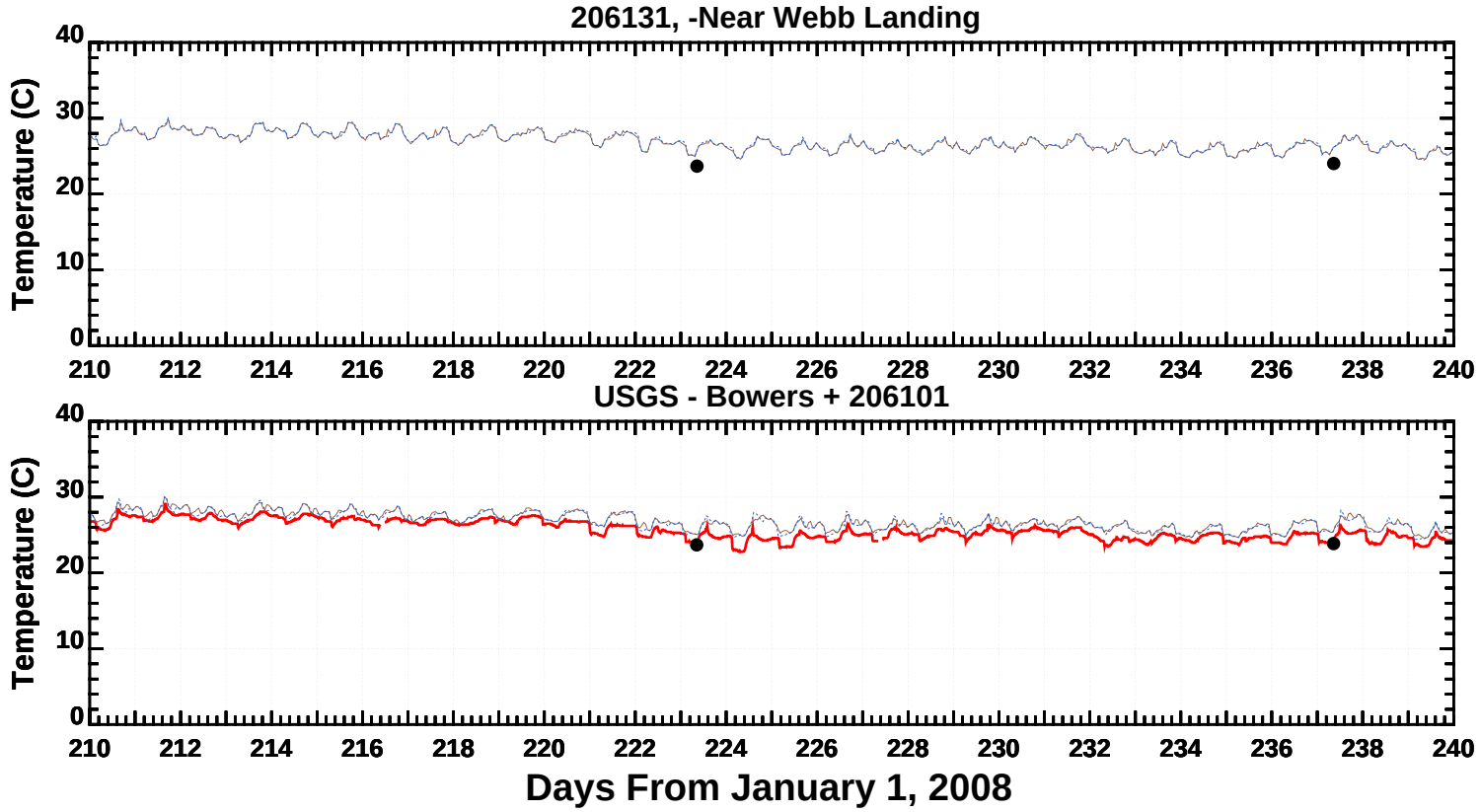
MODEL: ——— SURFACE

– – – – BOTTOM

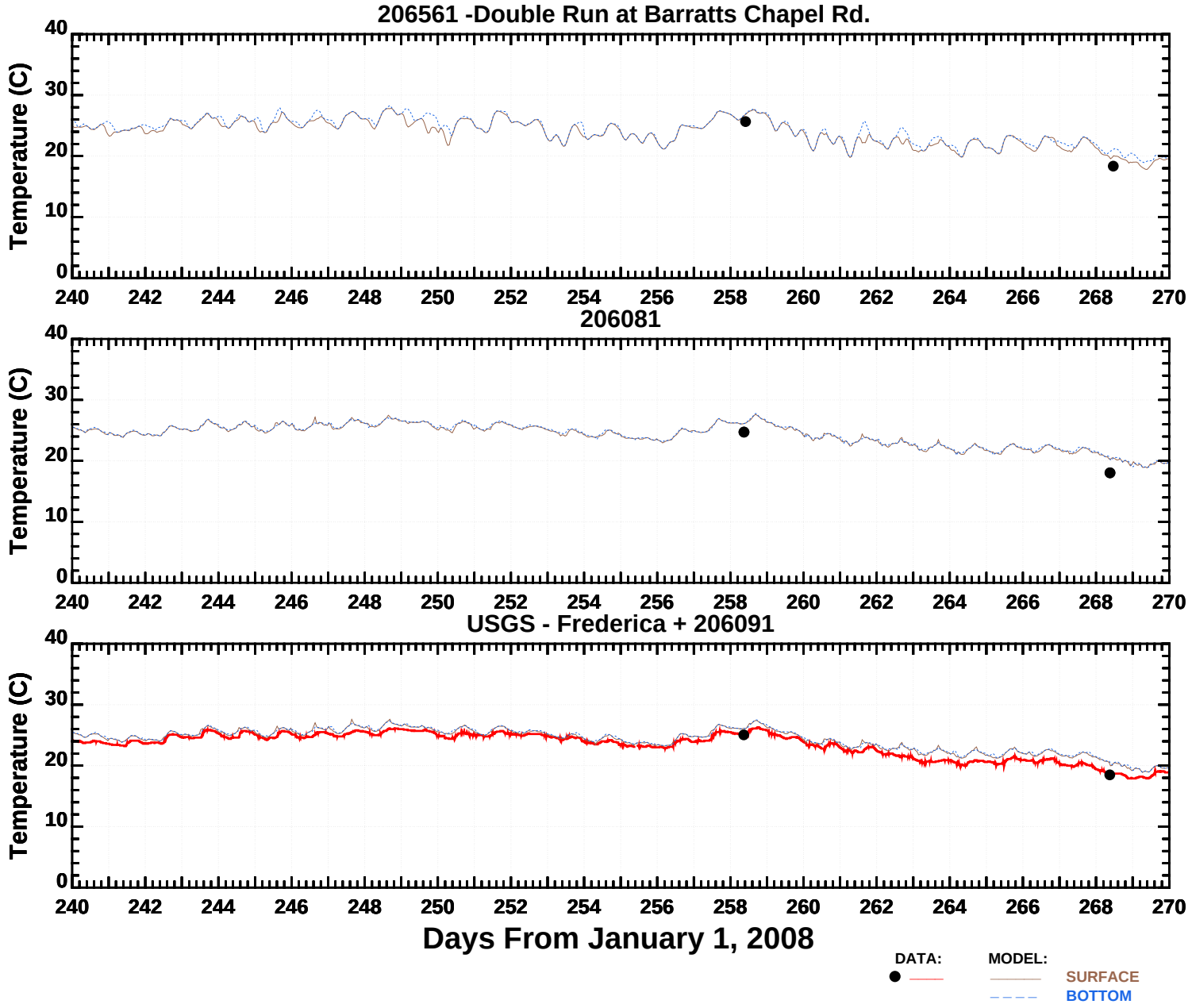


DATE: 1/22/2013 TIME: 13:16:29


206231 - WPCP Branch
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Temperature (C)
0
10
20
30
40
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

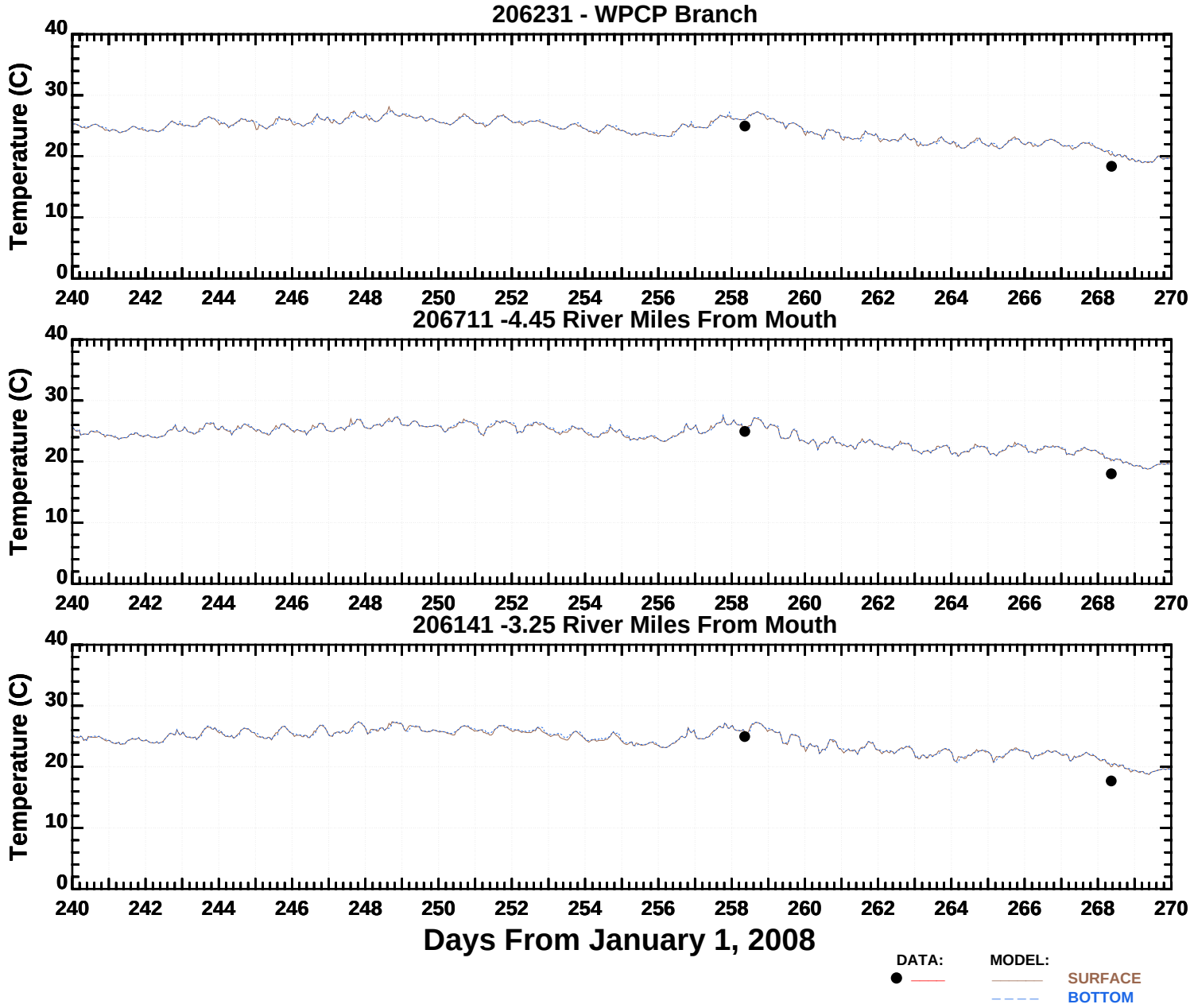


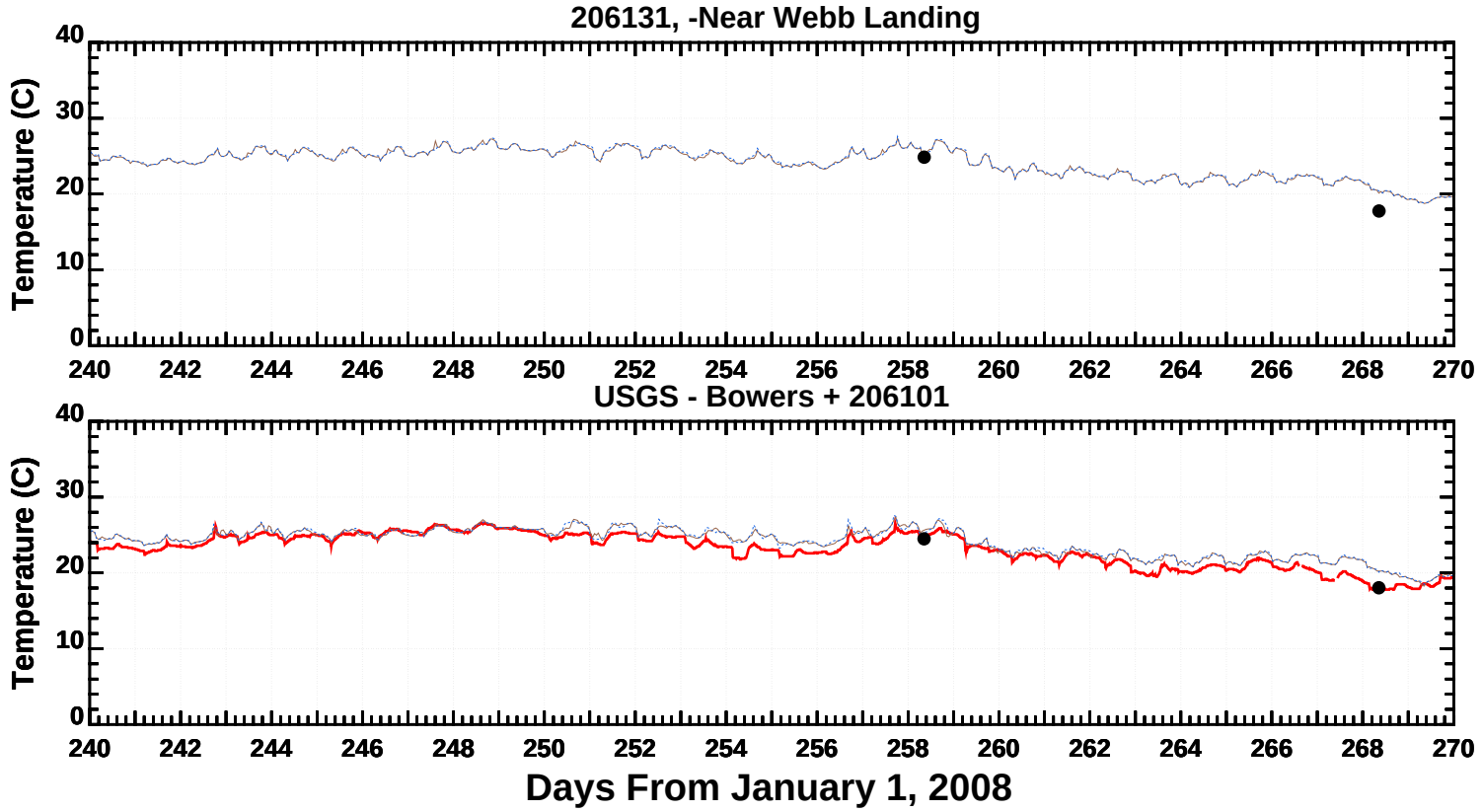
DATA: ● MODEL: SURFACE BOTTOM



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:16:37


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM

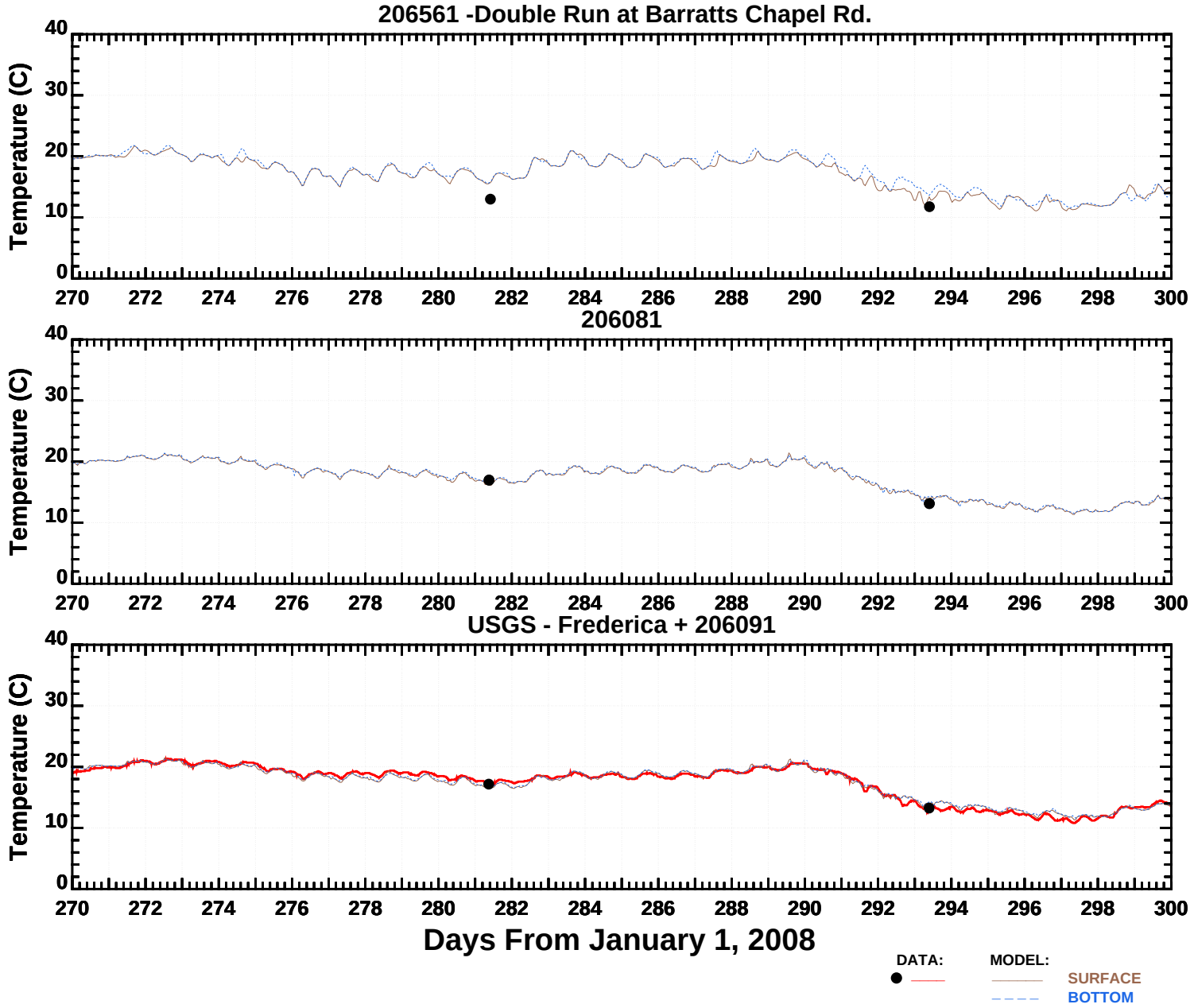


DATA: ● ——

MODEL: ——— SURFACE

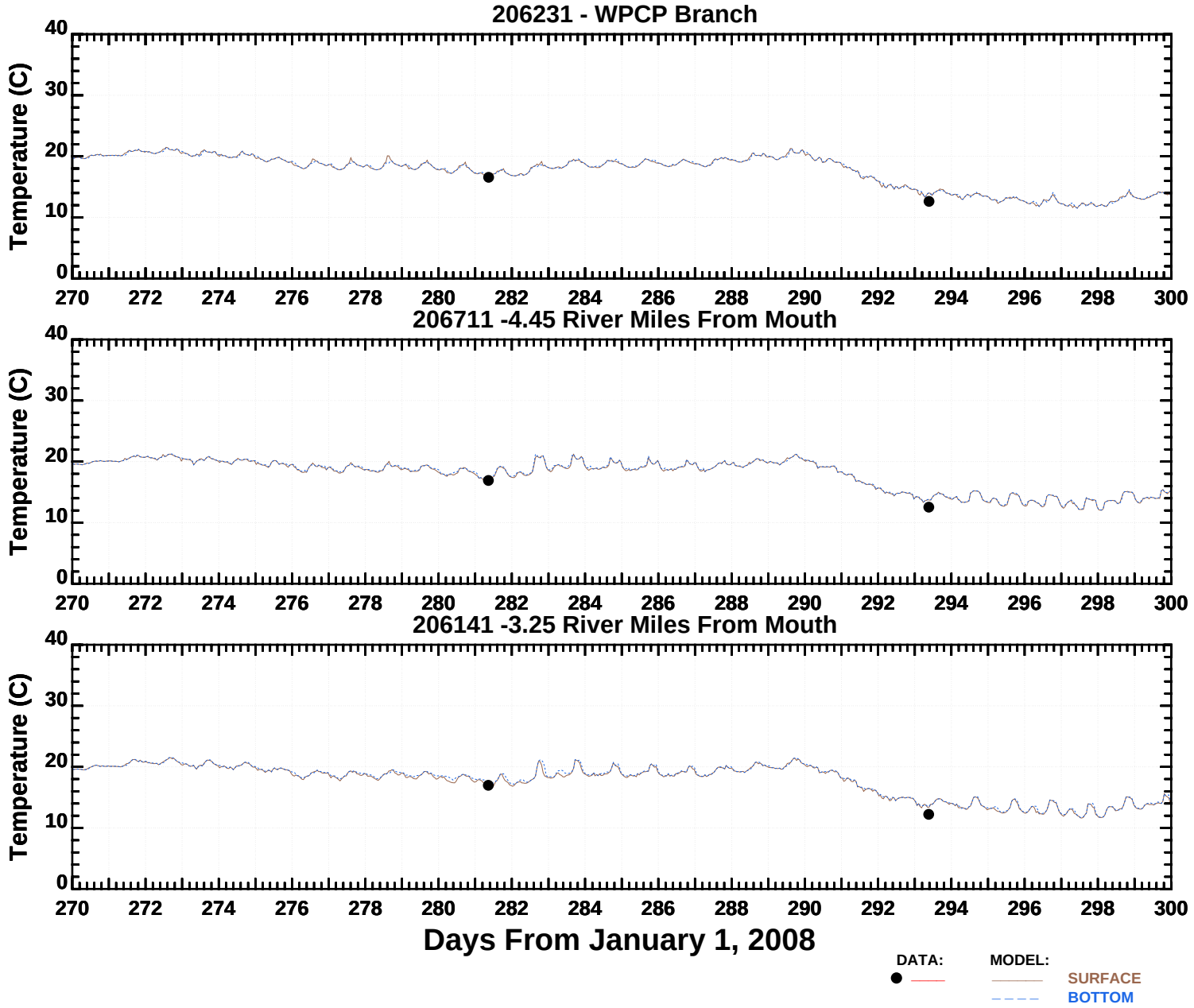
– – – – BOTTOM

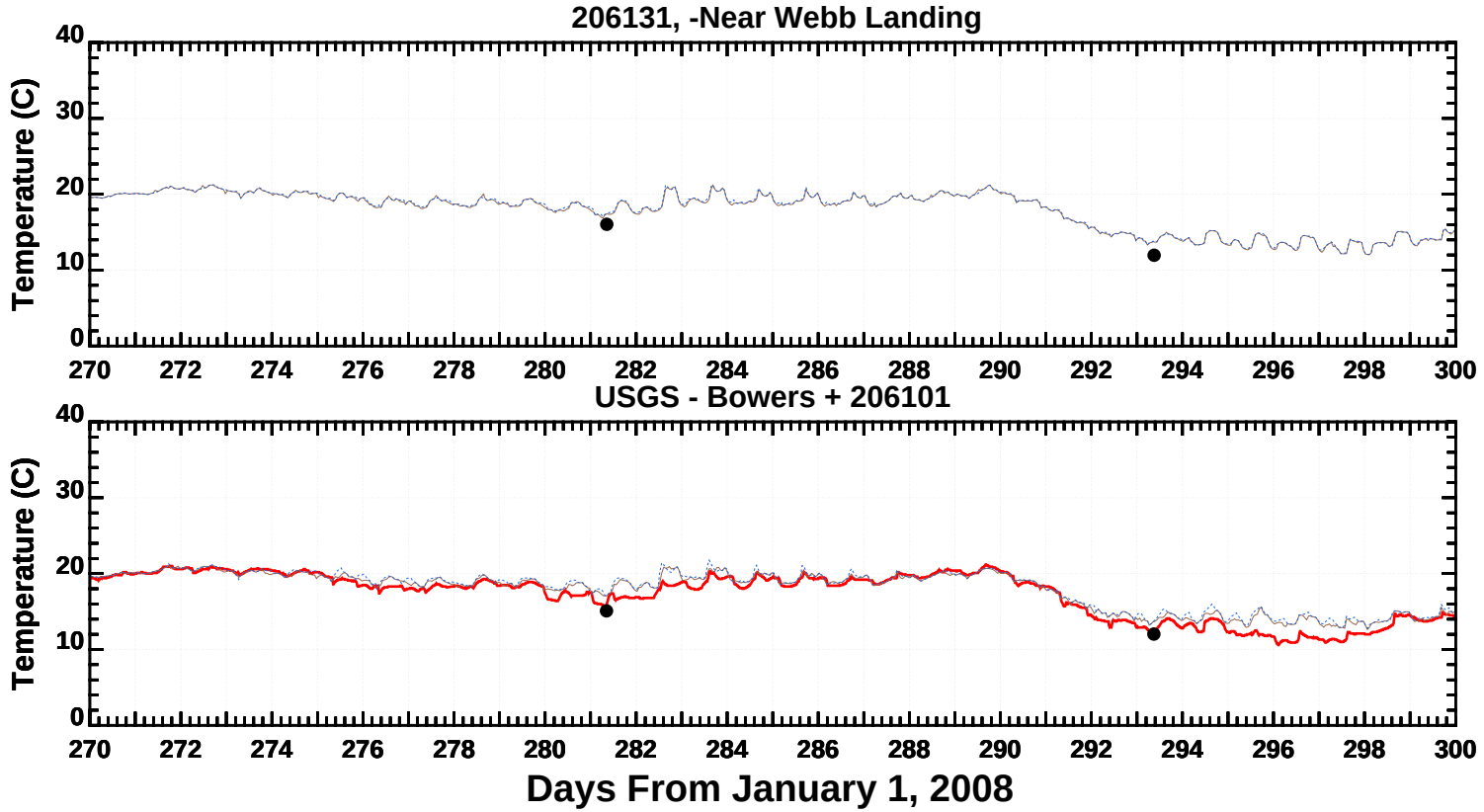
DATE: 1/22/2013 TIME: 13:16:37



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp
Page 1 of 3
08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:16:45

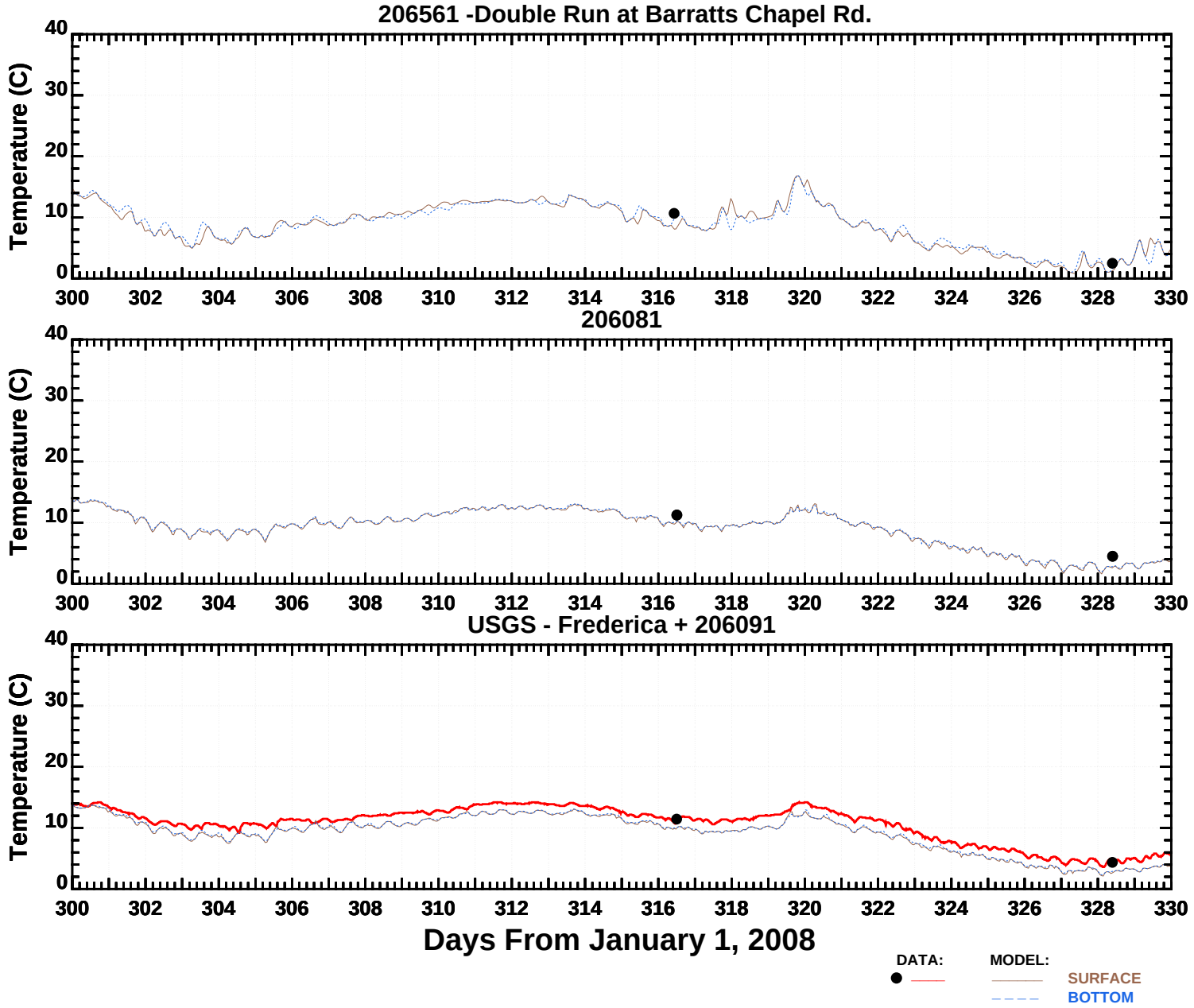

206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



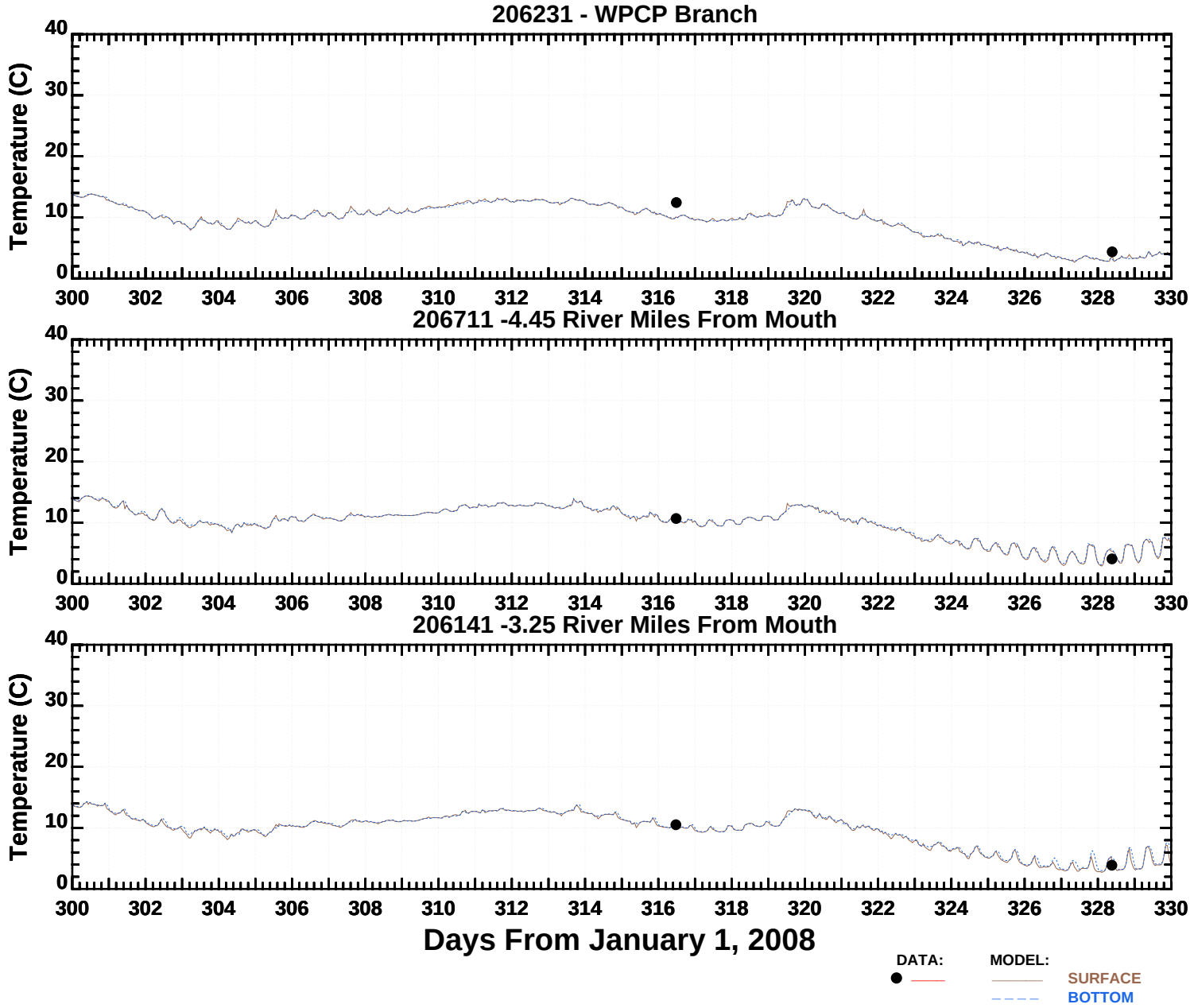
DATA: ● ——

MODEL: ——— SURFACE

– – – – BOTTOM



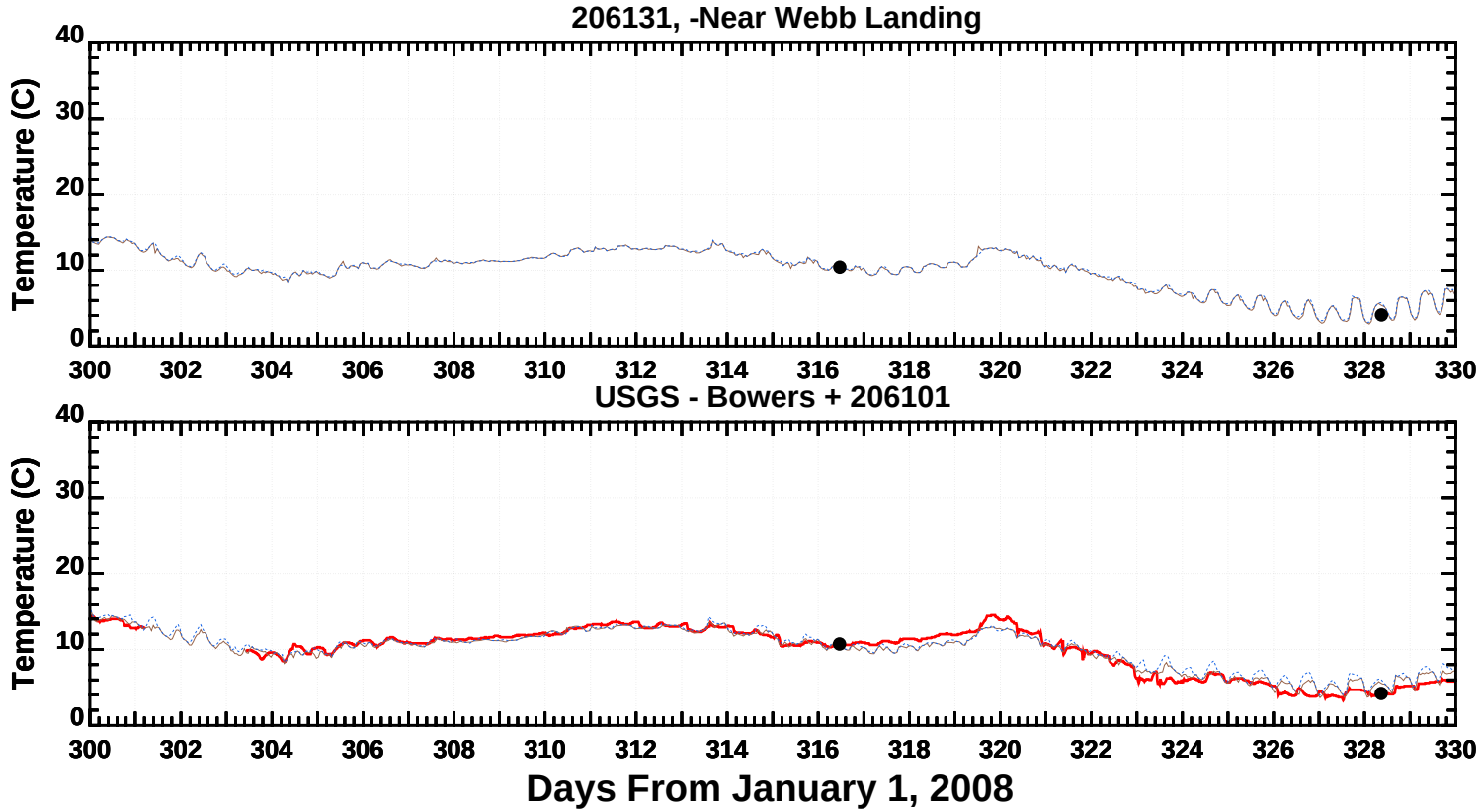
DATE: 1/22/2013 TIME: 13:16:52



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/TANDS/tempReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 13:16:52

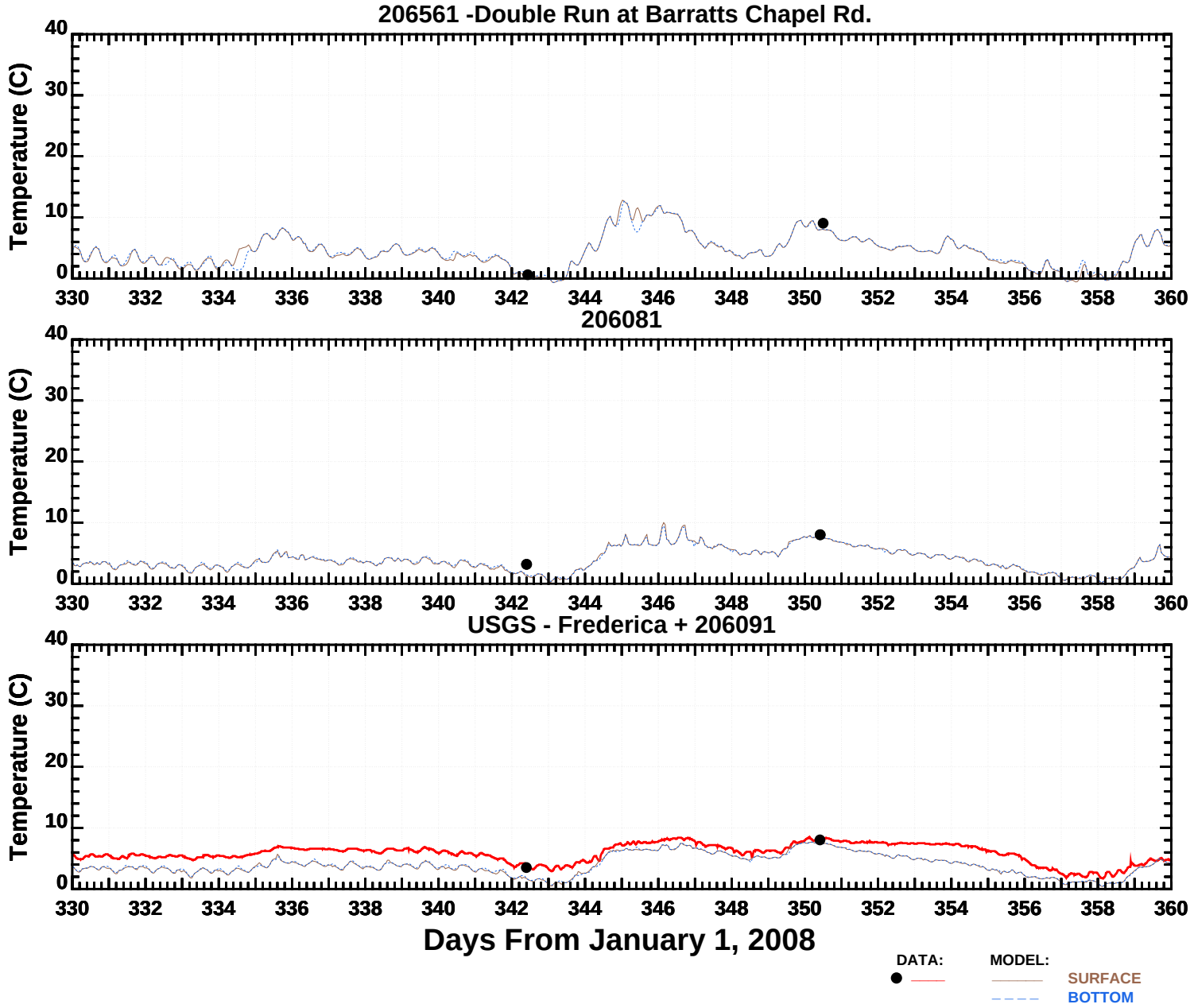


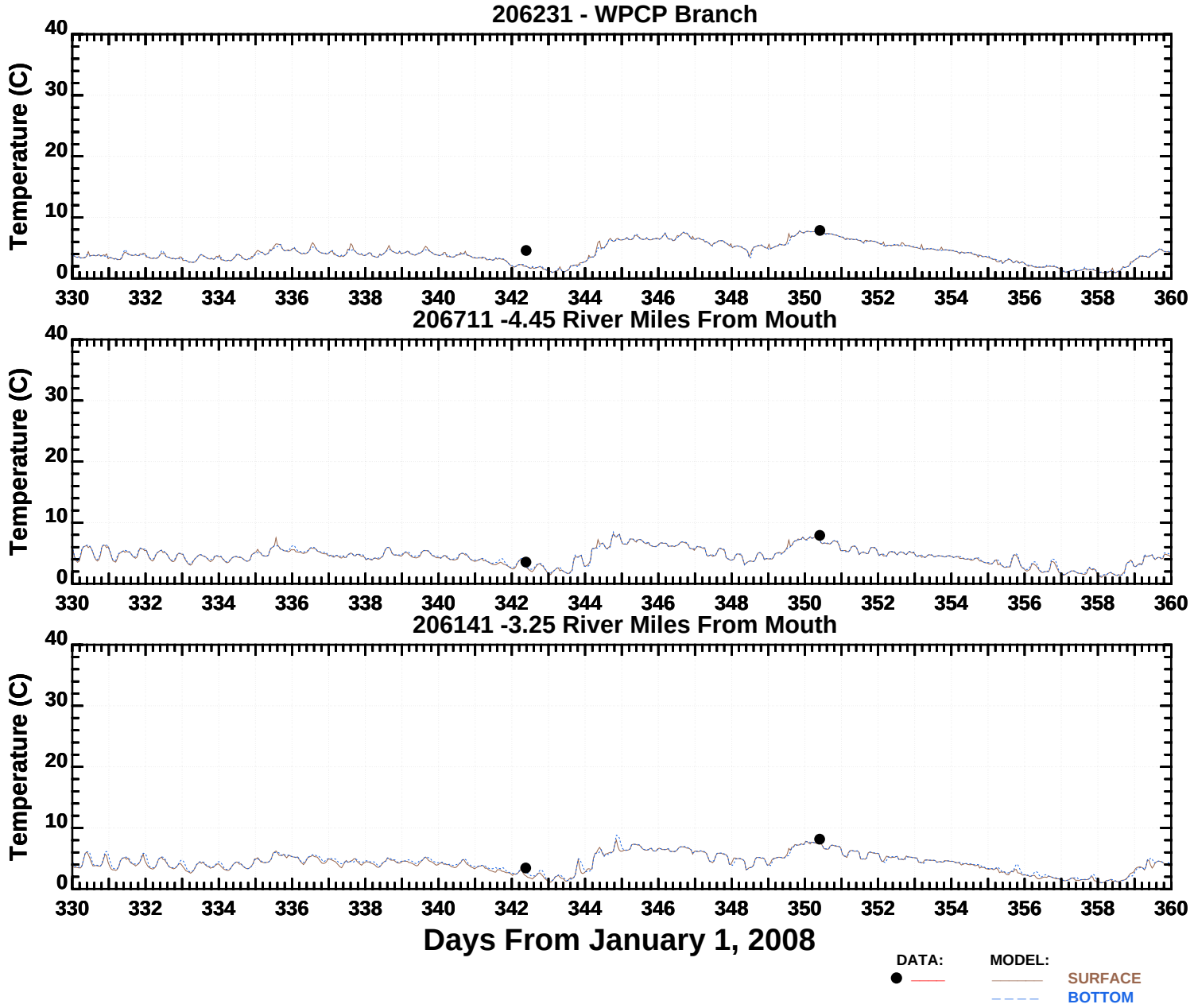
DATA: ● ——

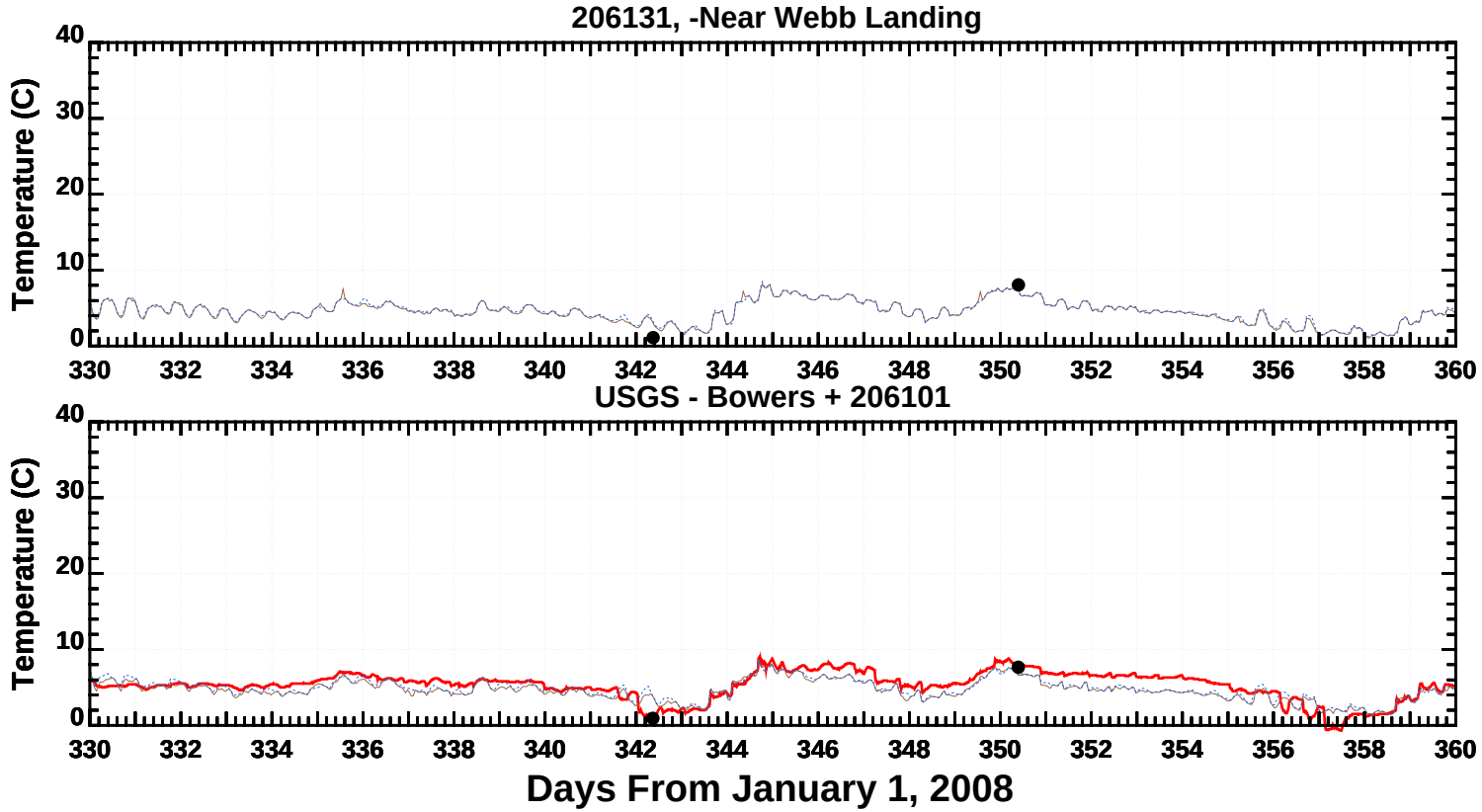
MODEL: ——— SURFACE

– – – – BOTTOM

DATE: 1/22/2013 TIME: 13:16:52


206561 -Double Run at Barratts Chapel Rd.
Temperature (C)
40
30
20
10
0
330
332
334
336
338
340
342
344
346
348
350
352
354
356
358
360
206081
USGS - Frederica + 206091
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM


206231 - WPCP Branch
Temperature (C)
206711 -4.45 River Miles From Mouth
206141 -3.25 River Miles From Mouth
Days From January 1, 2008
DATA:
MODEL:
SURFACE
BOTTOM



DATA: ● ——

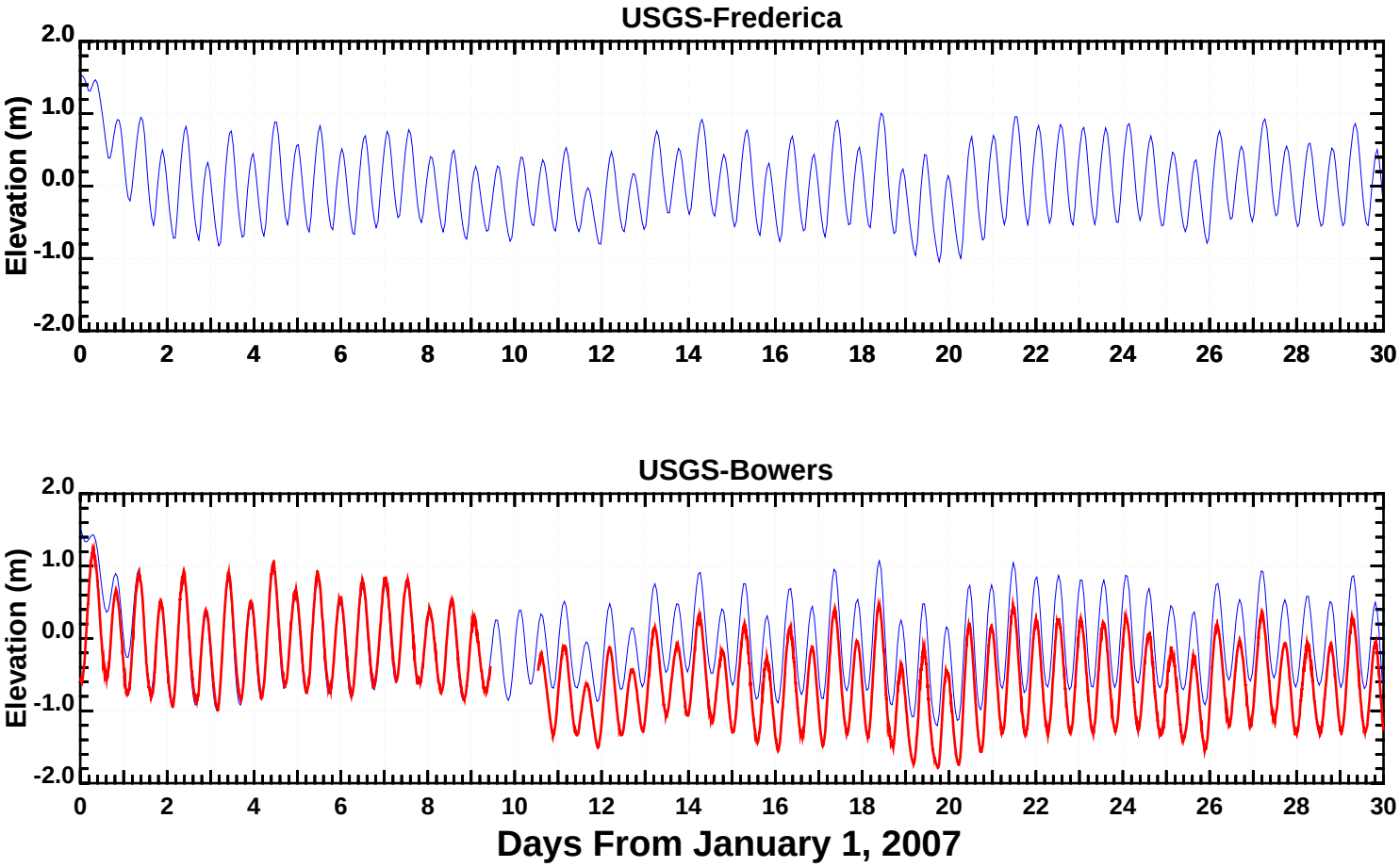
MODEL: ——— SURFACE

– – – – BOTTOM

DATE: 1/22/2013 TIME: 13:17: 0

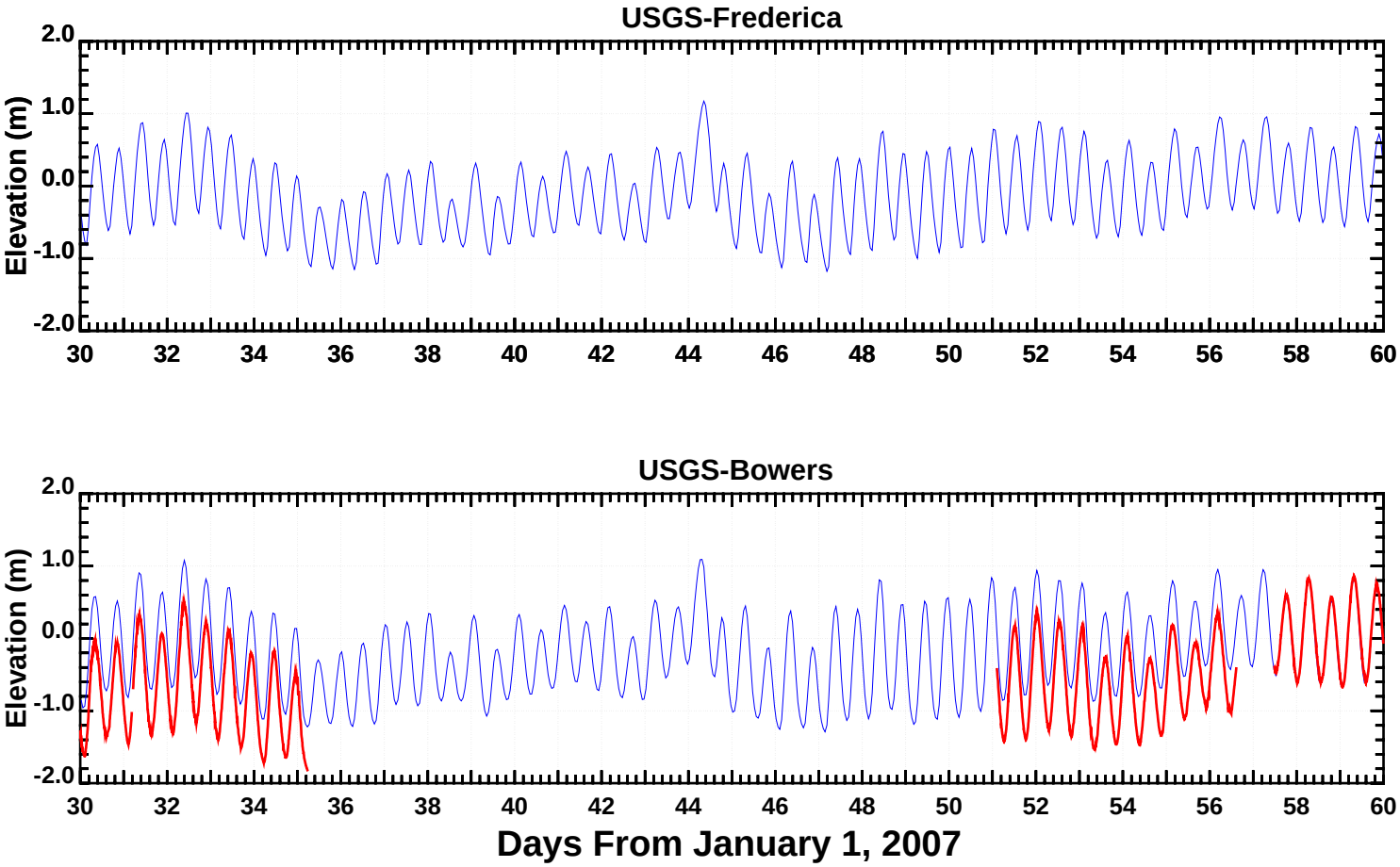
APPENDIX 5

HYDRODYNAMIC MODEL
WATER ELEVATION
CALIBRATION/VALIDATION
FIGURES



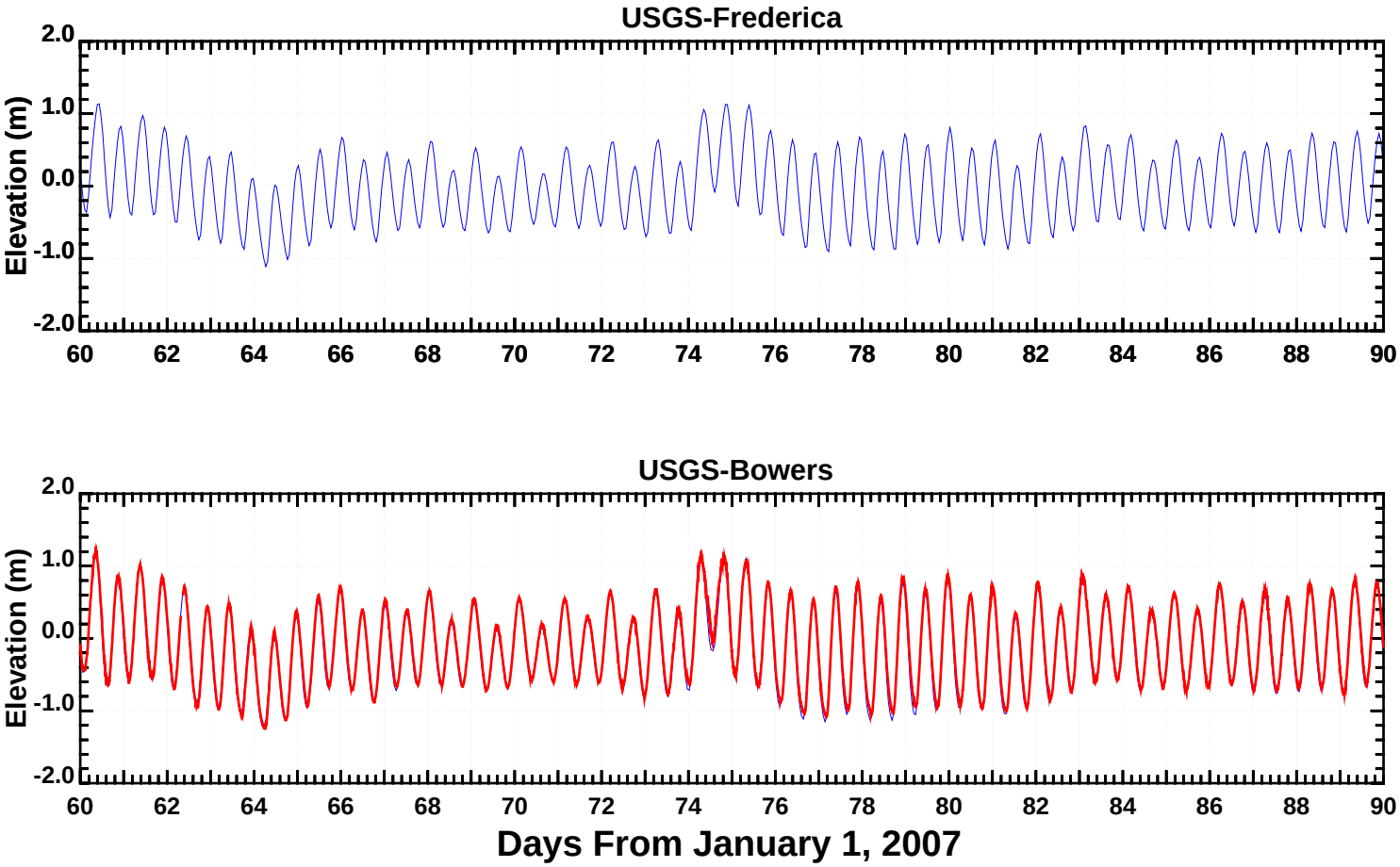
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



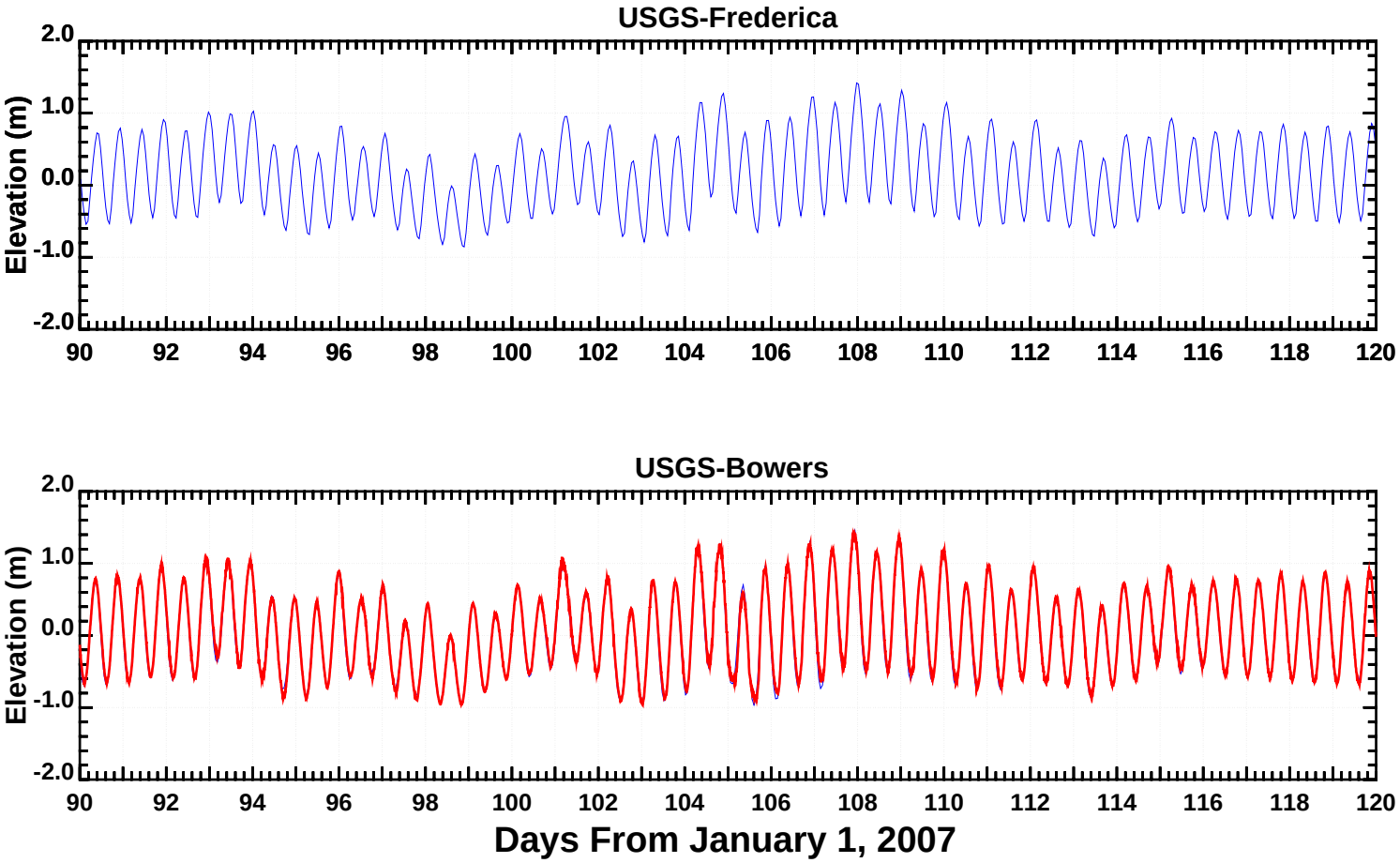
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



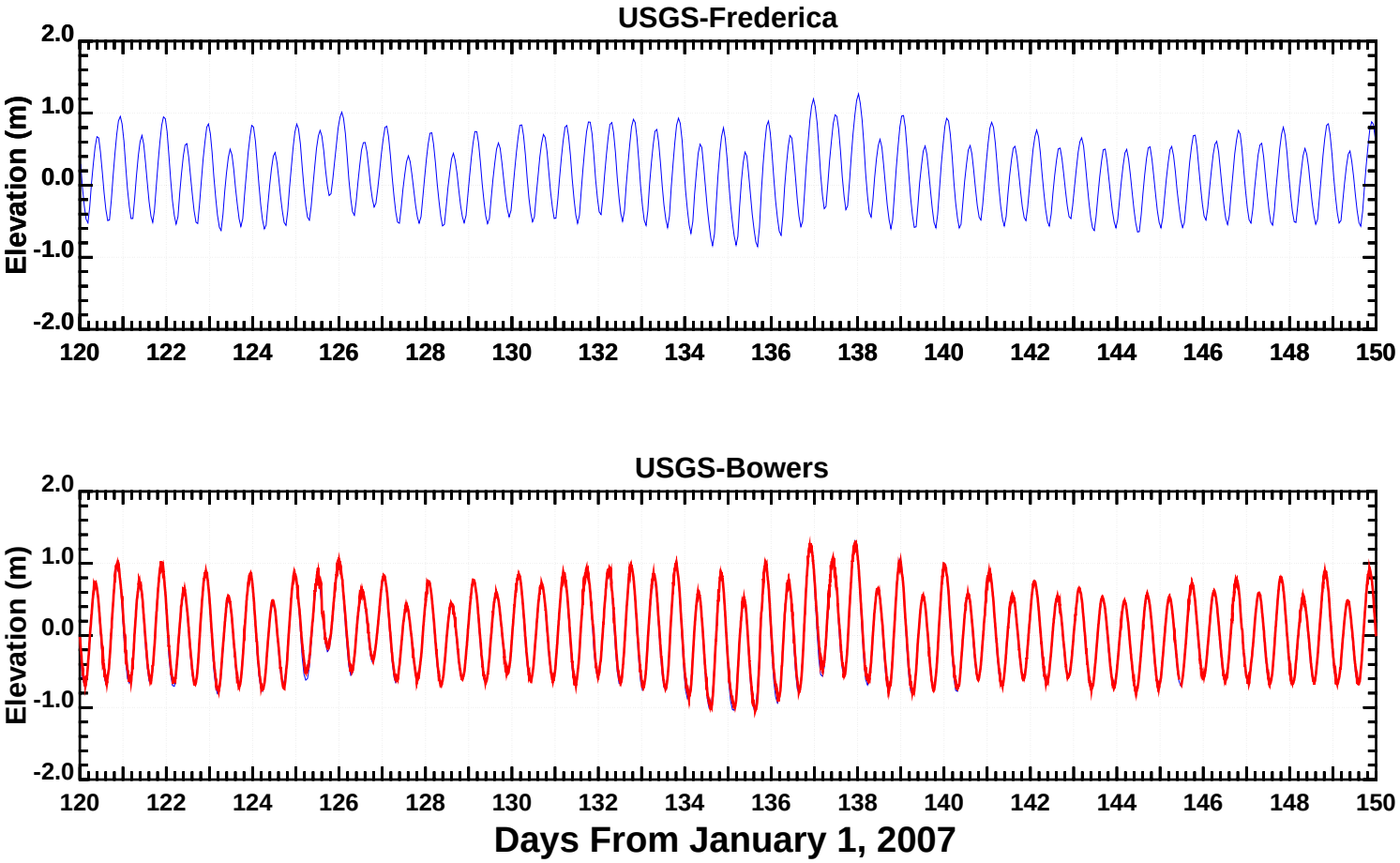
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



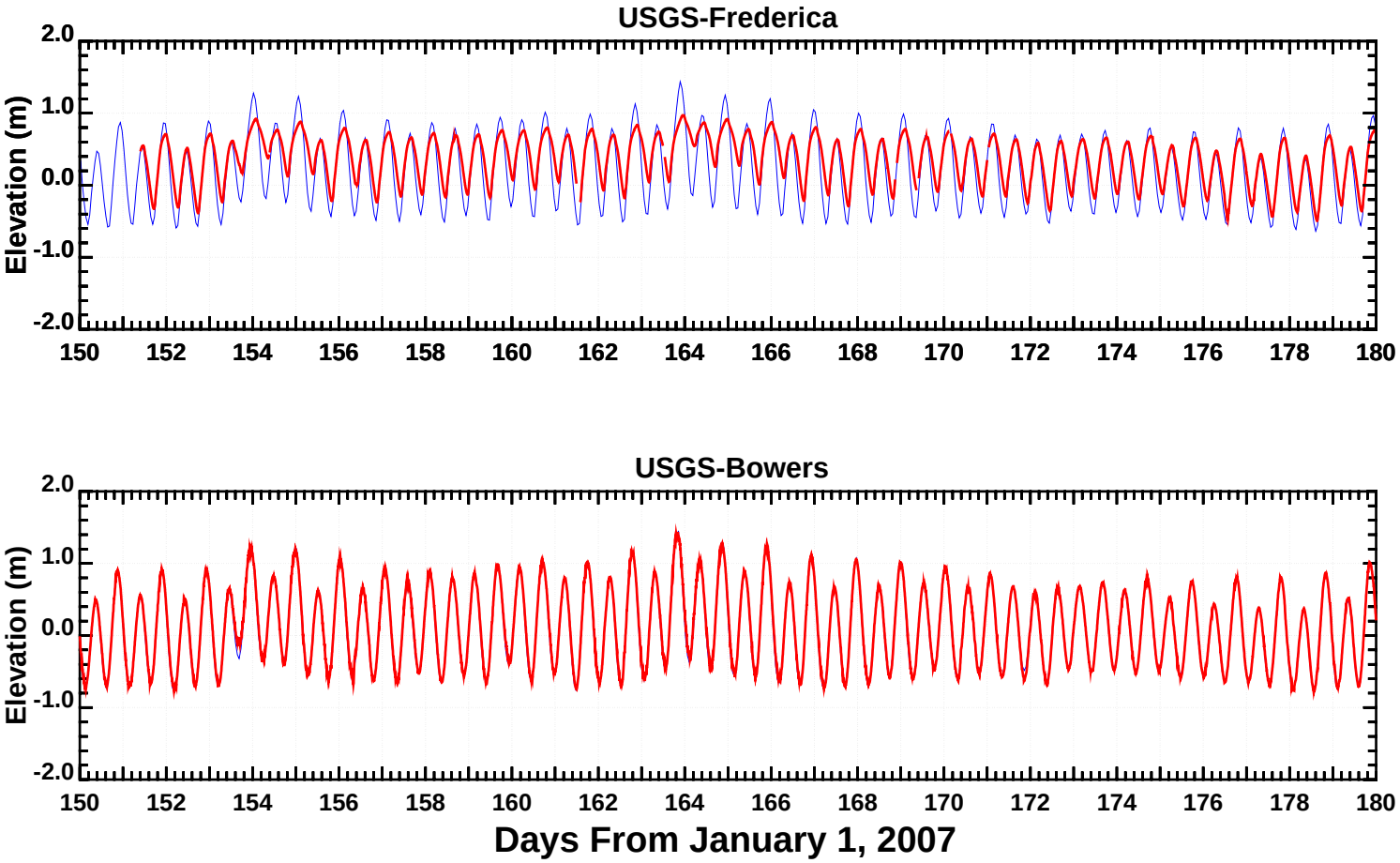
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



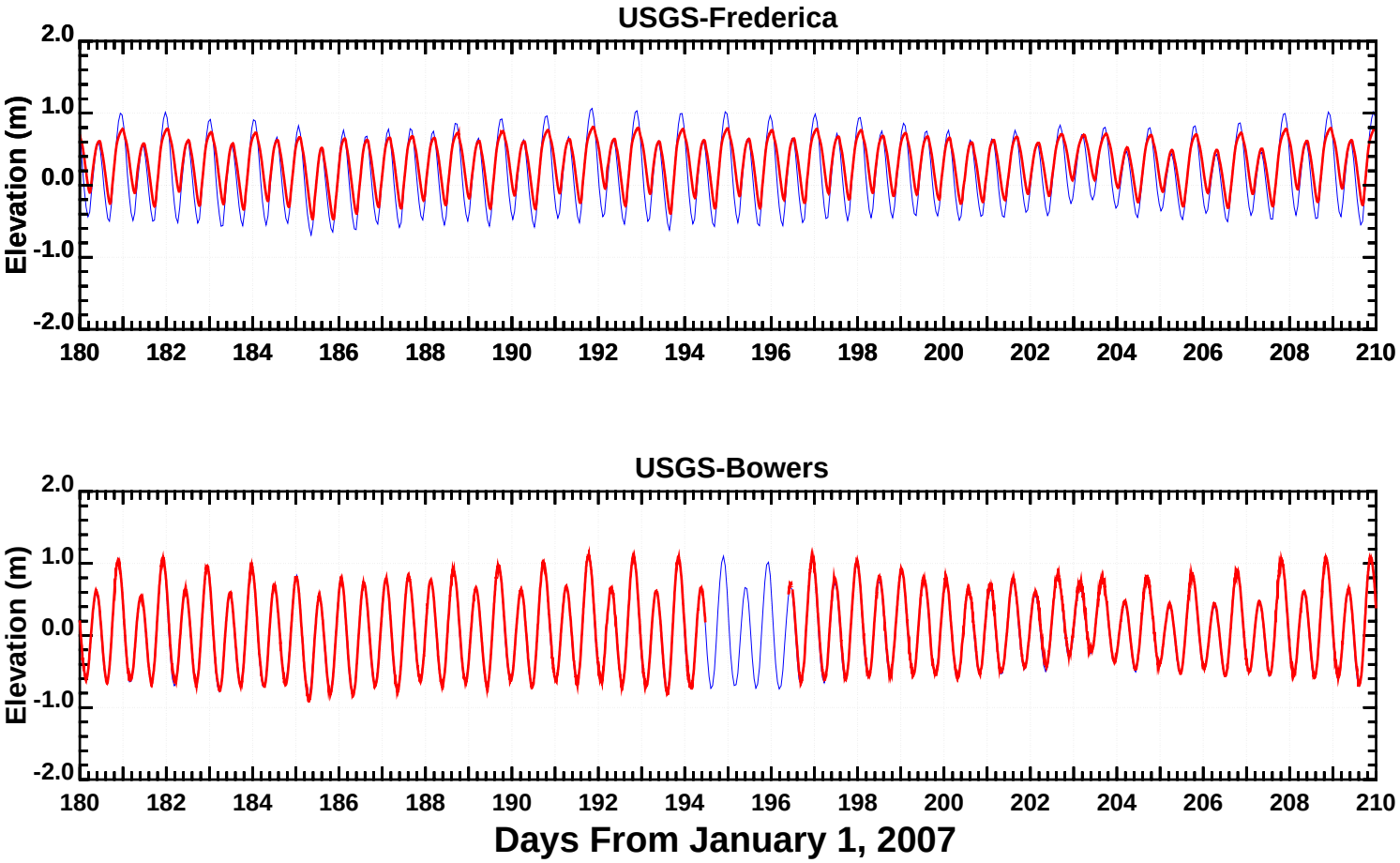
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



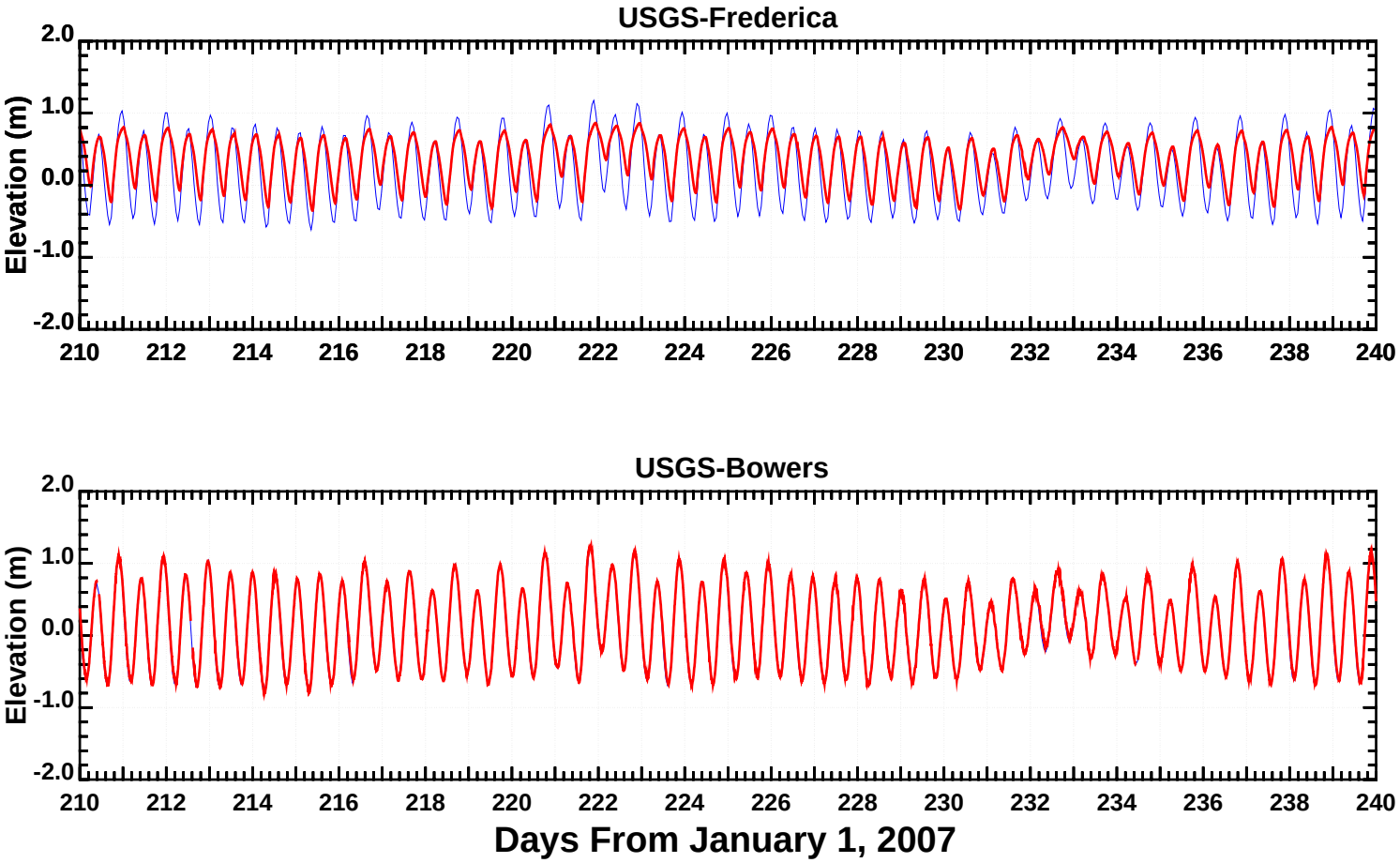
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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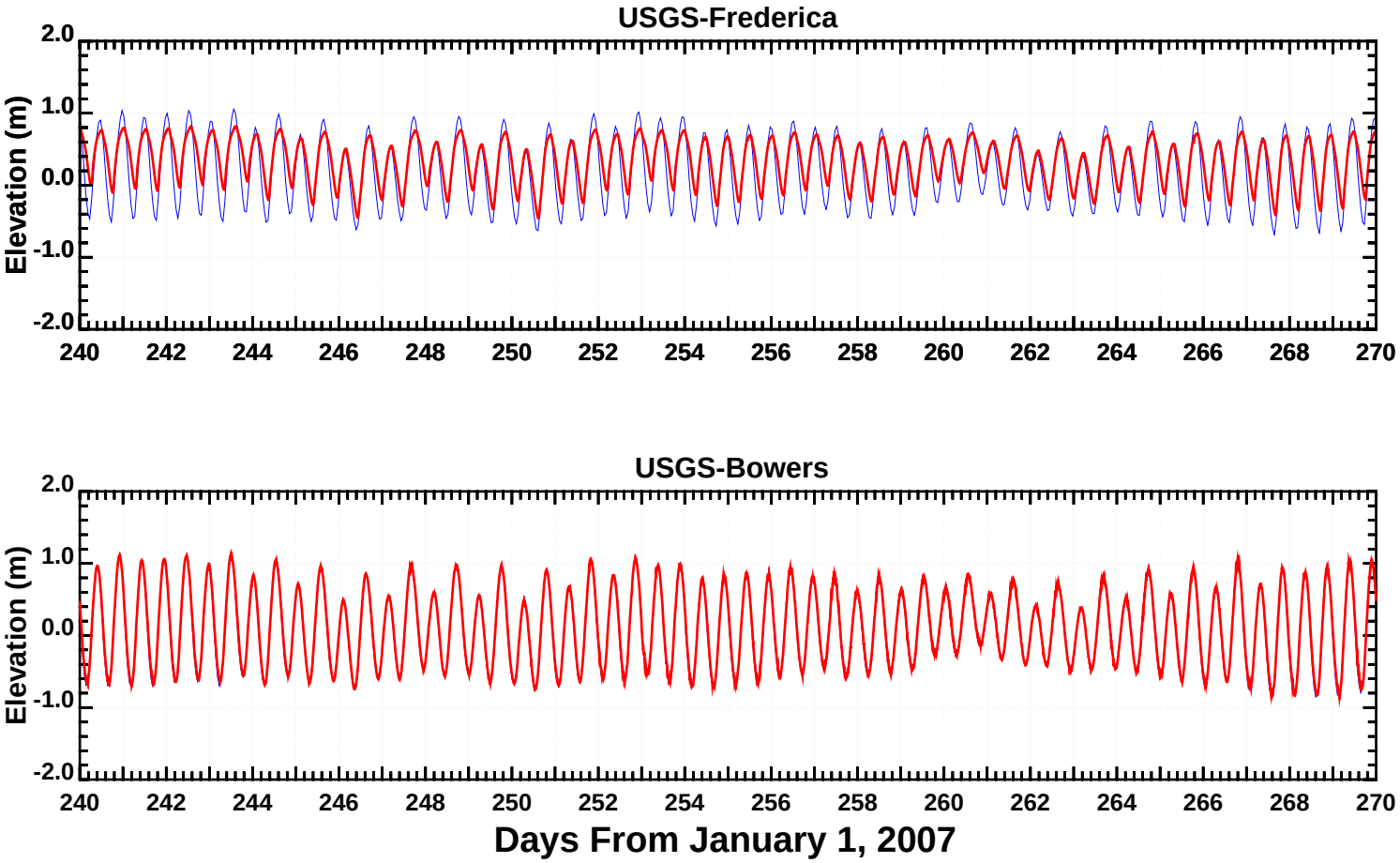
DATE: 1/22/2013 TIME: 1:14:16



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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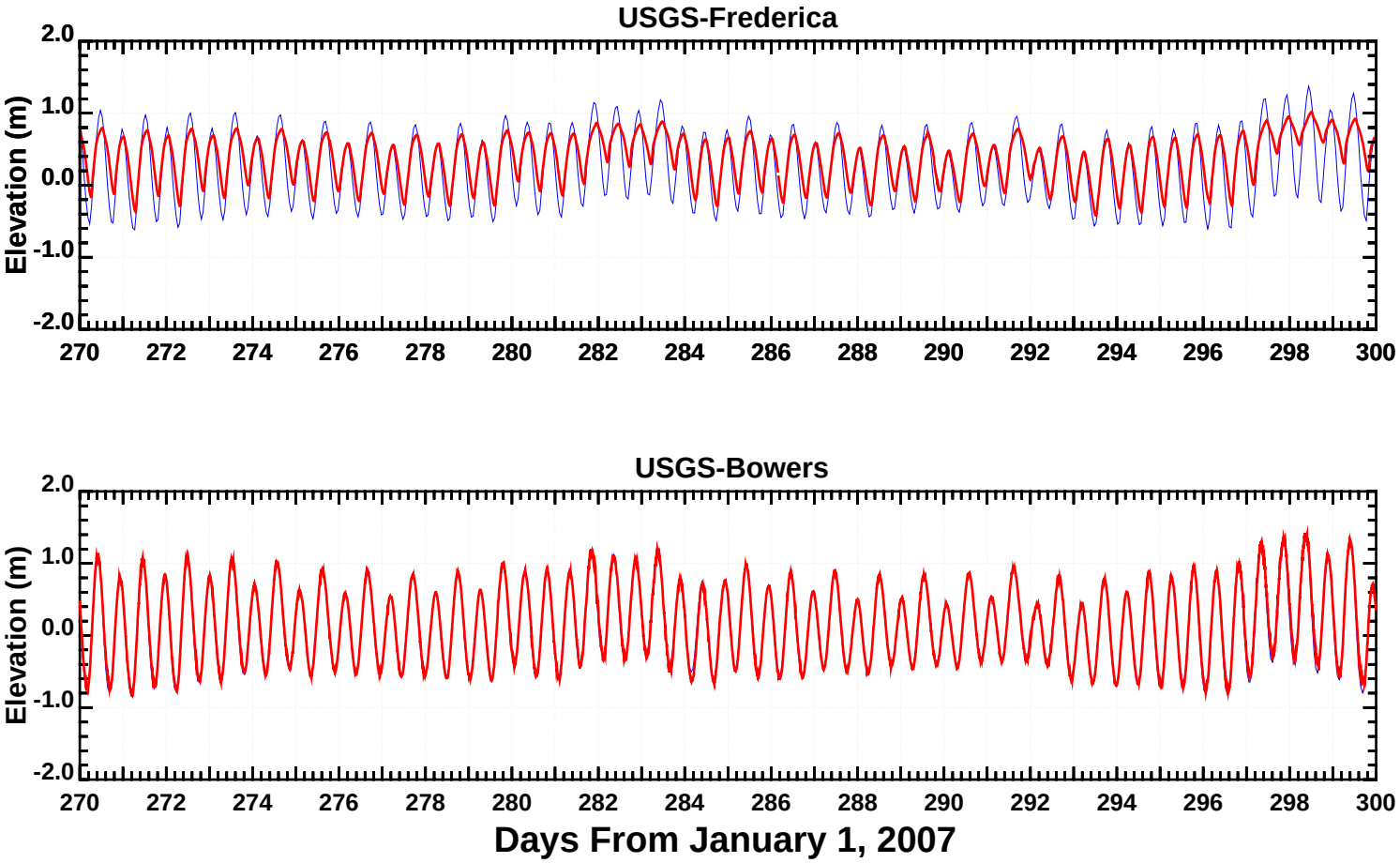
DATE: 1/22/2013 TIME: 1:14:22



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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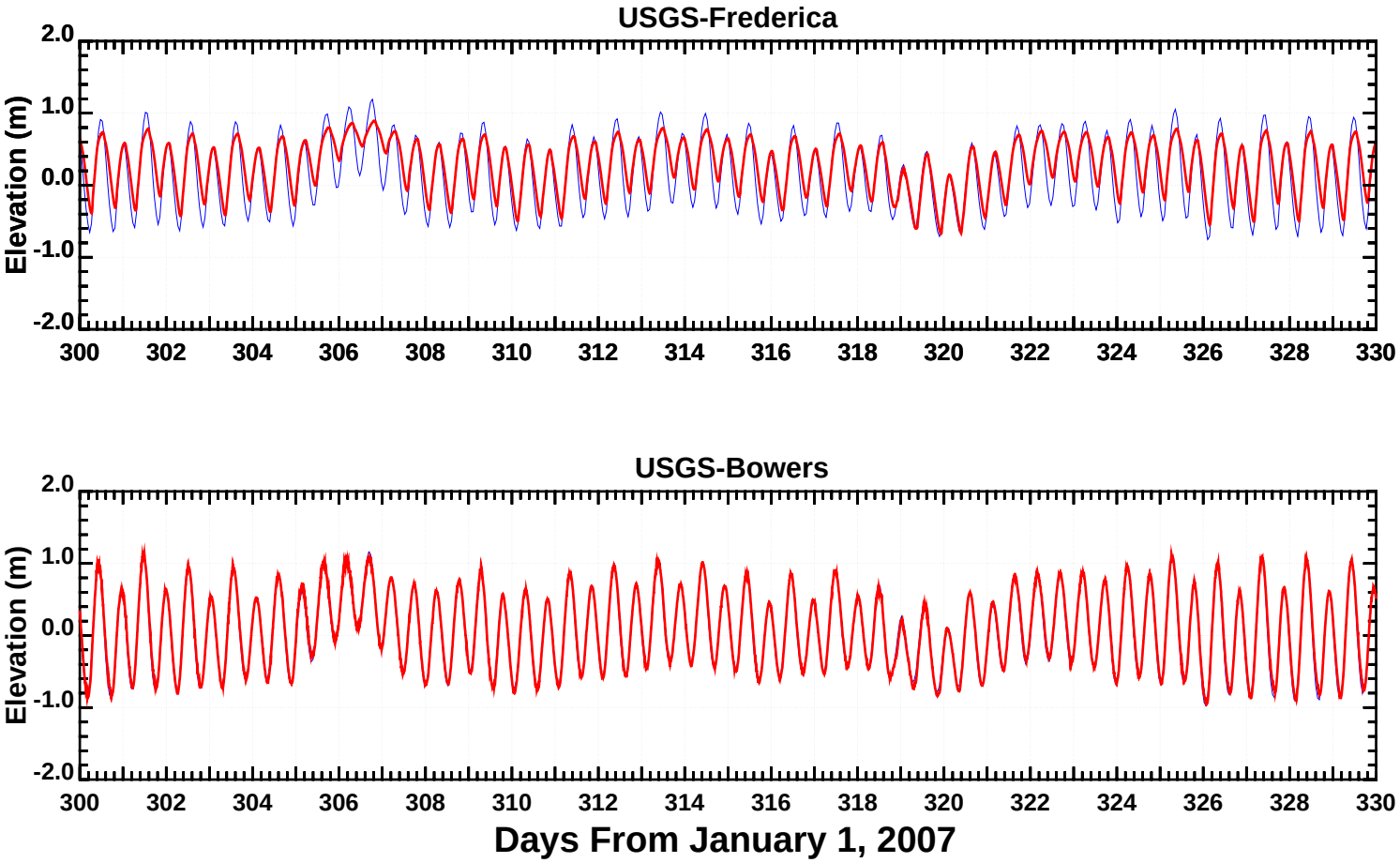
DATE: 1/22/2013 TIME: 1:14:27



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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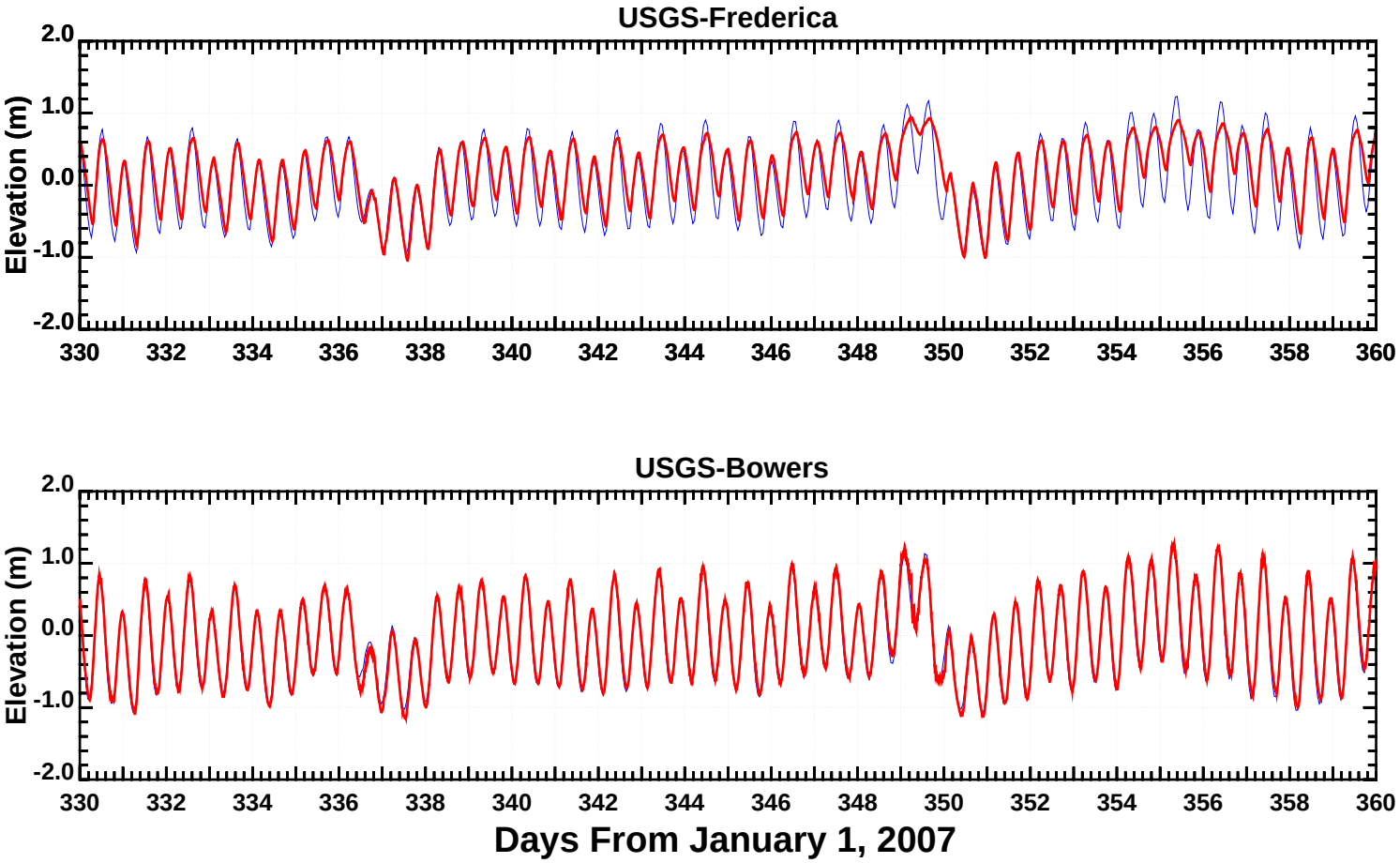
DATE: 1/22/2013 TIME: 1:14:34



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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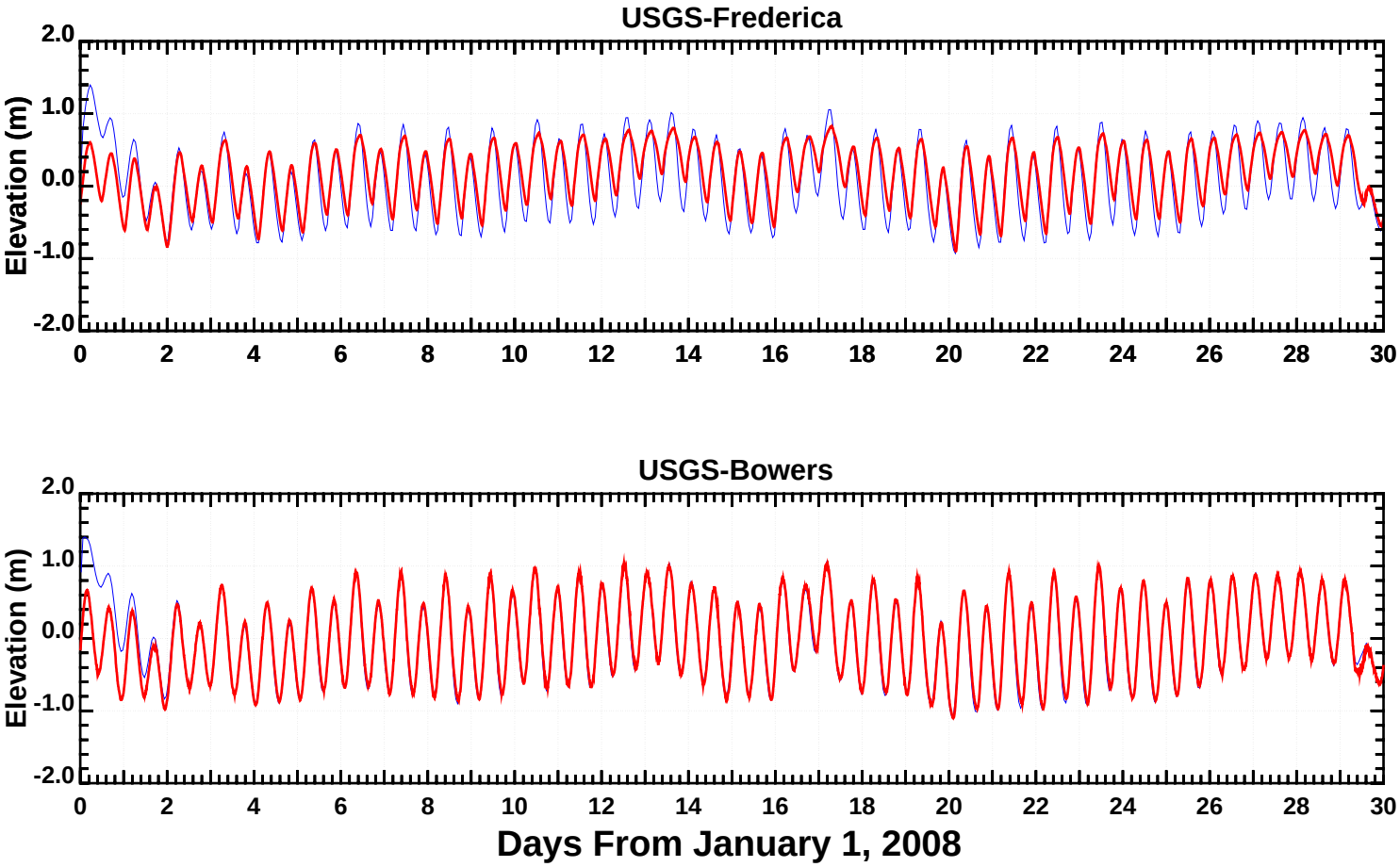
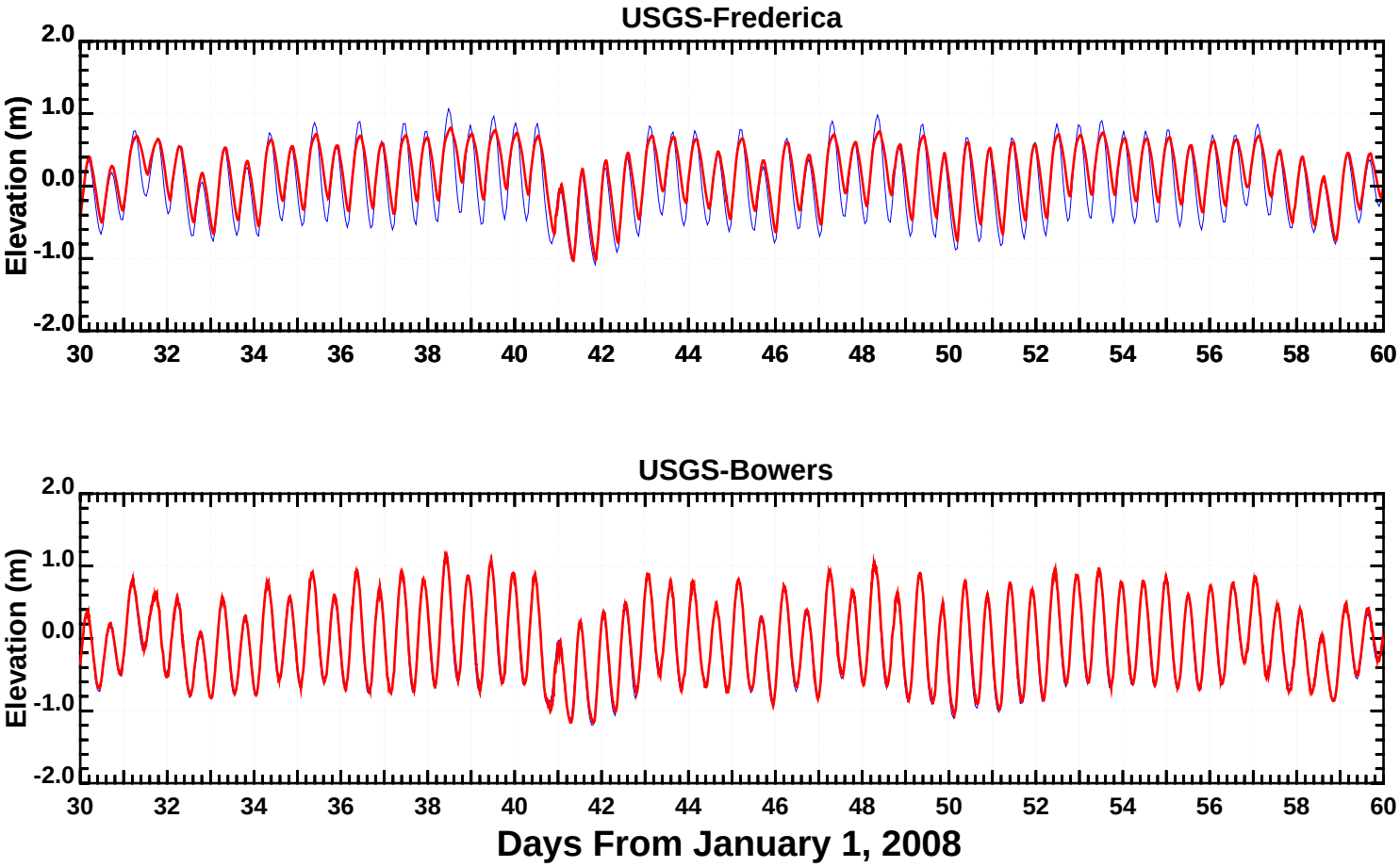
DATE: 1/22/2013 TIME: 1:14:40



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

DATE: 1/22/2013 TIME: 0:59:52



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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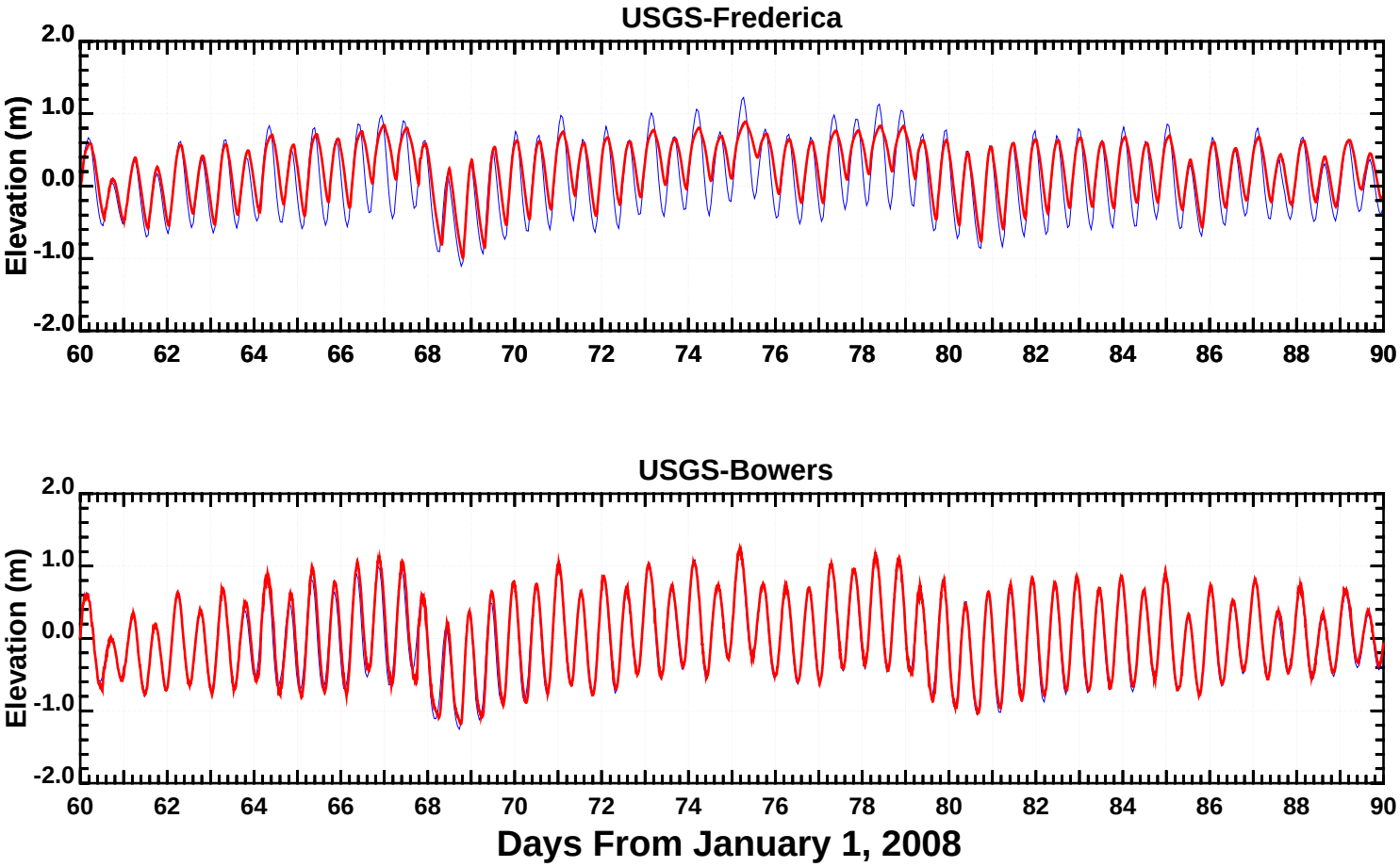
DATE: 1/22/2013 TIME: 0:59:57



DNREC Study
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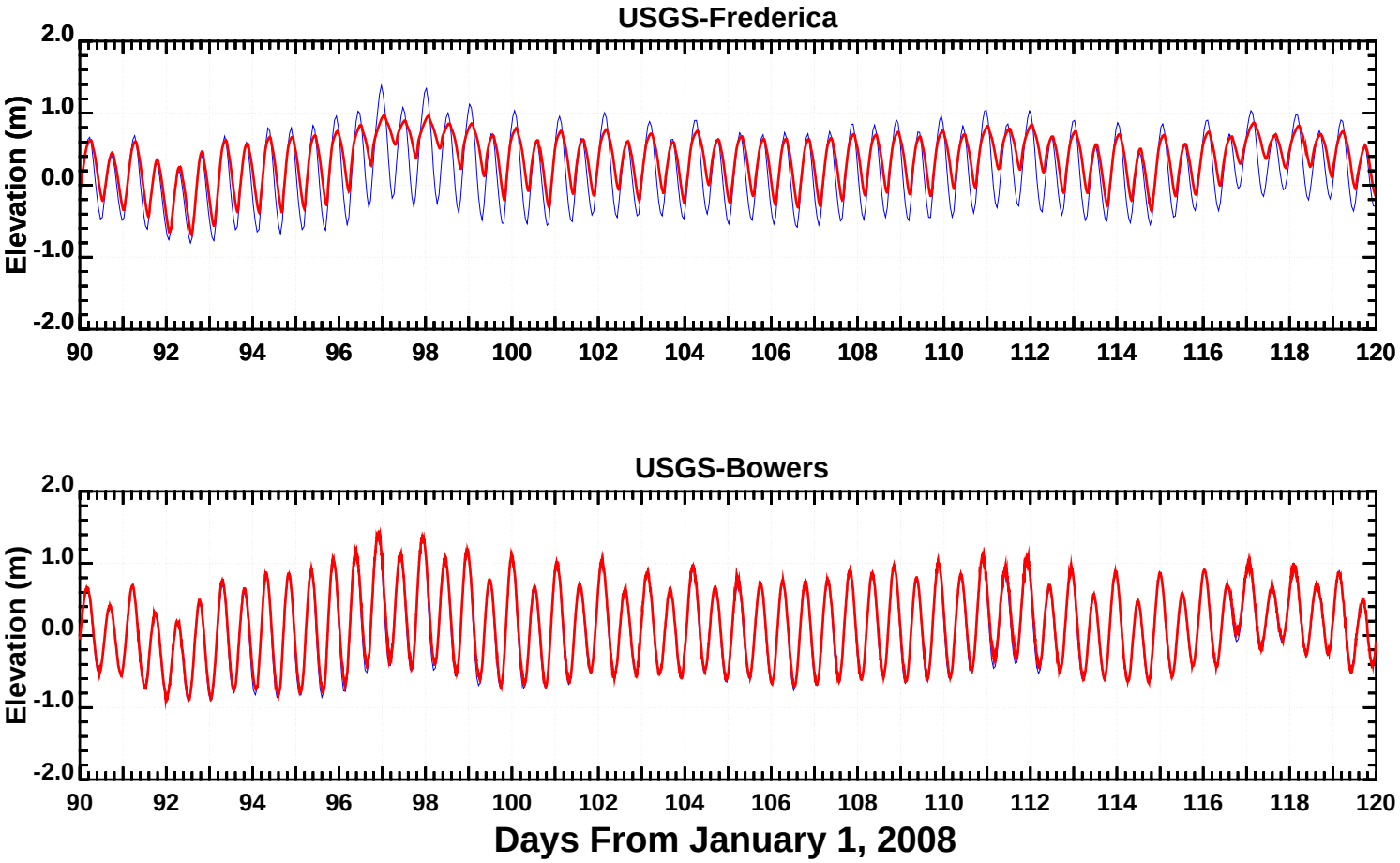

DNREC Study
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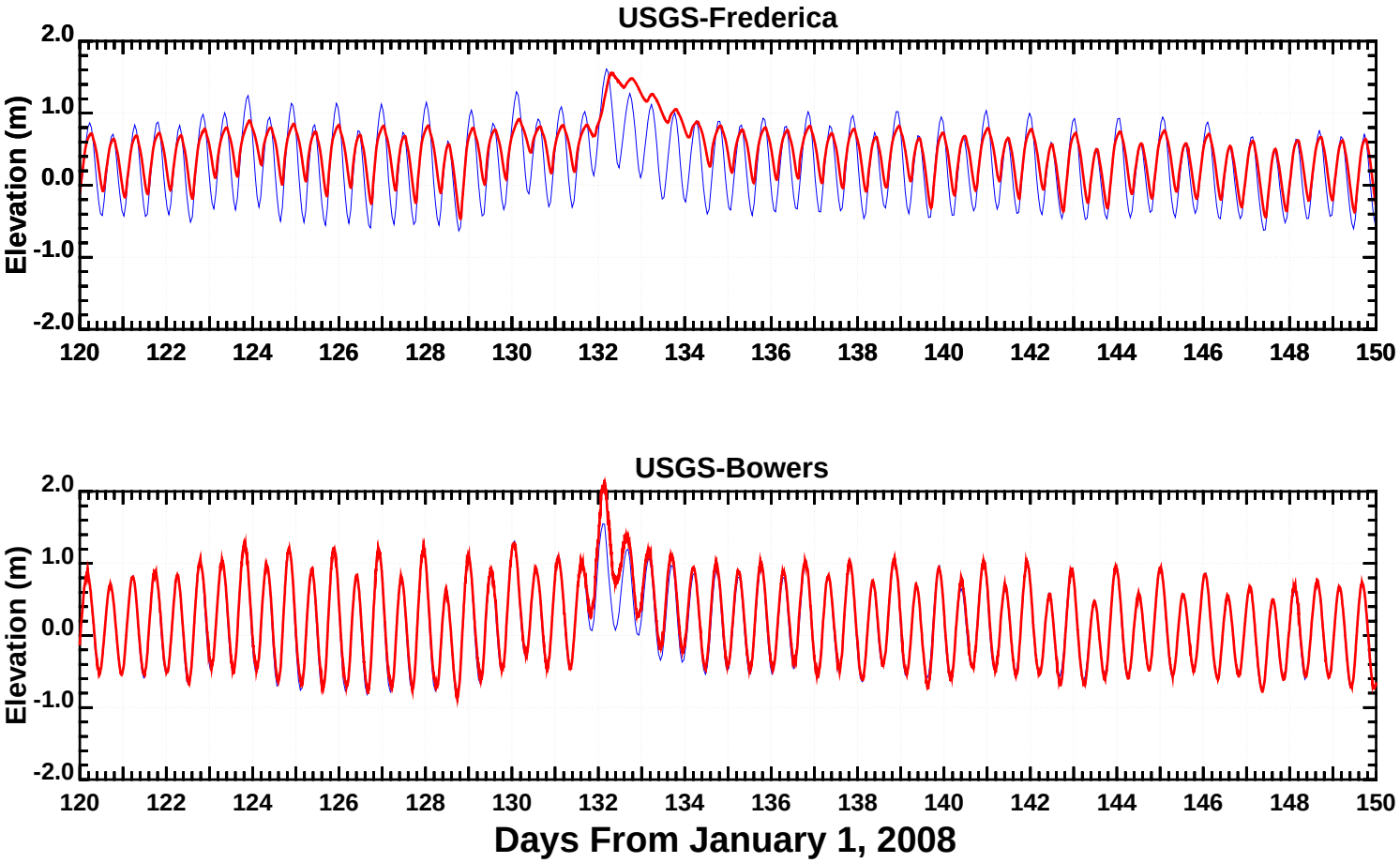

DNREC Study
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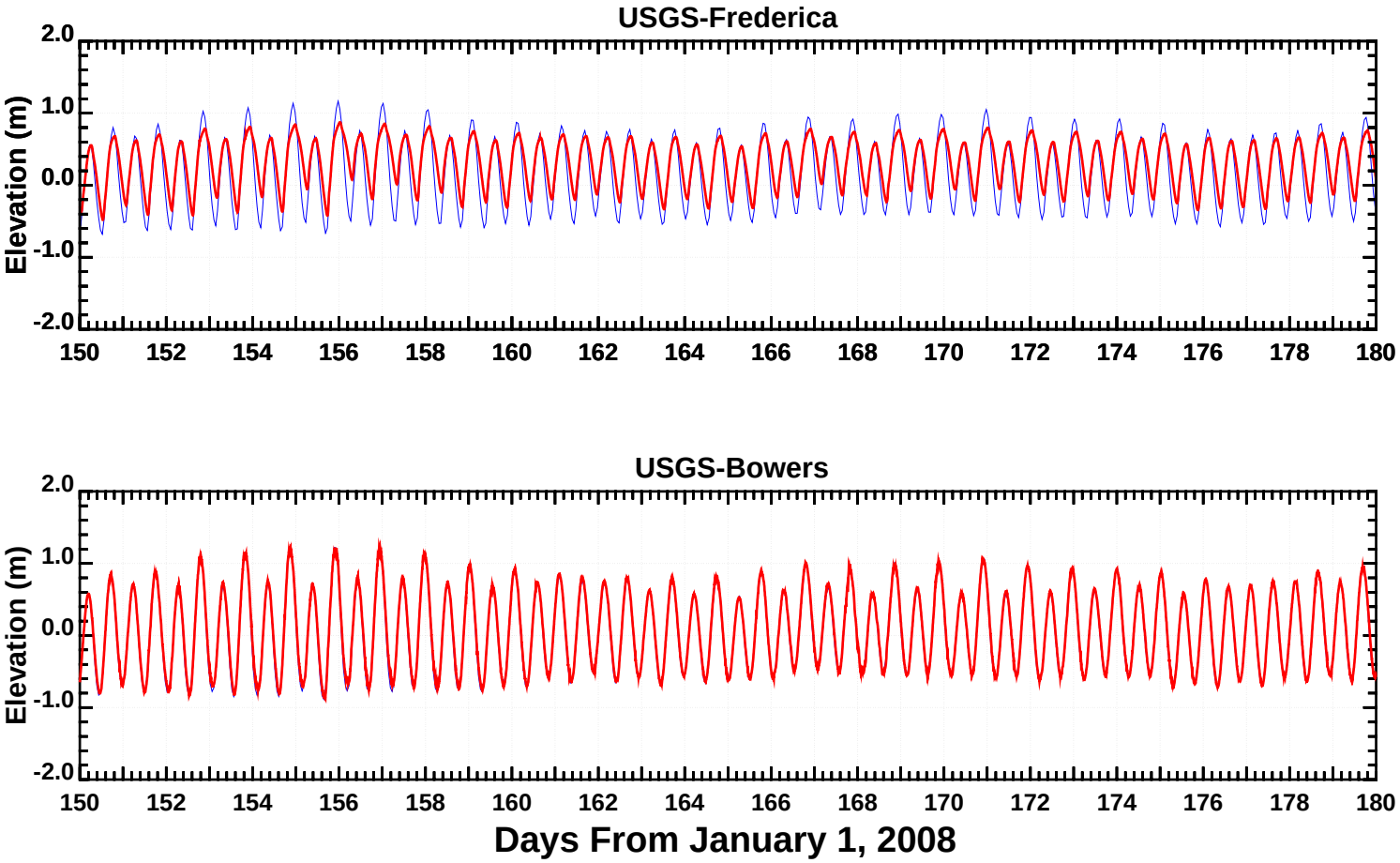

DNREC Study
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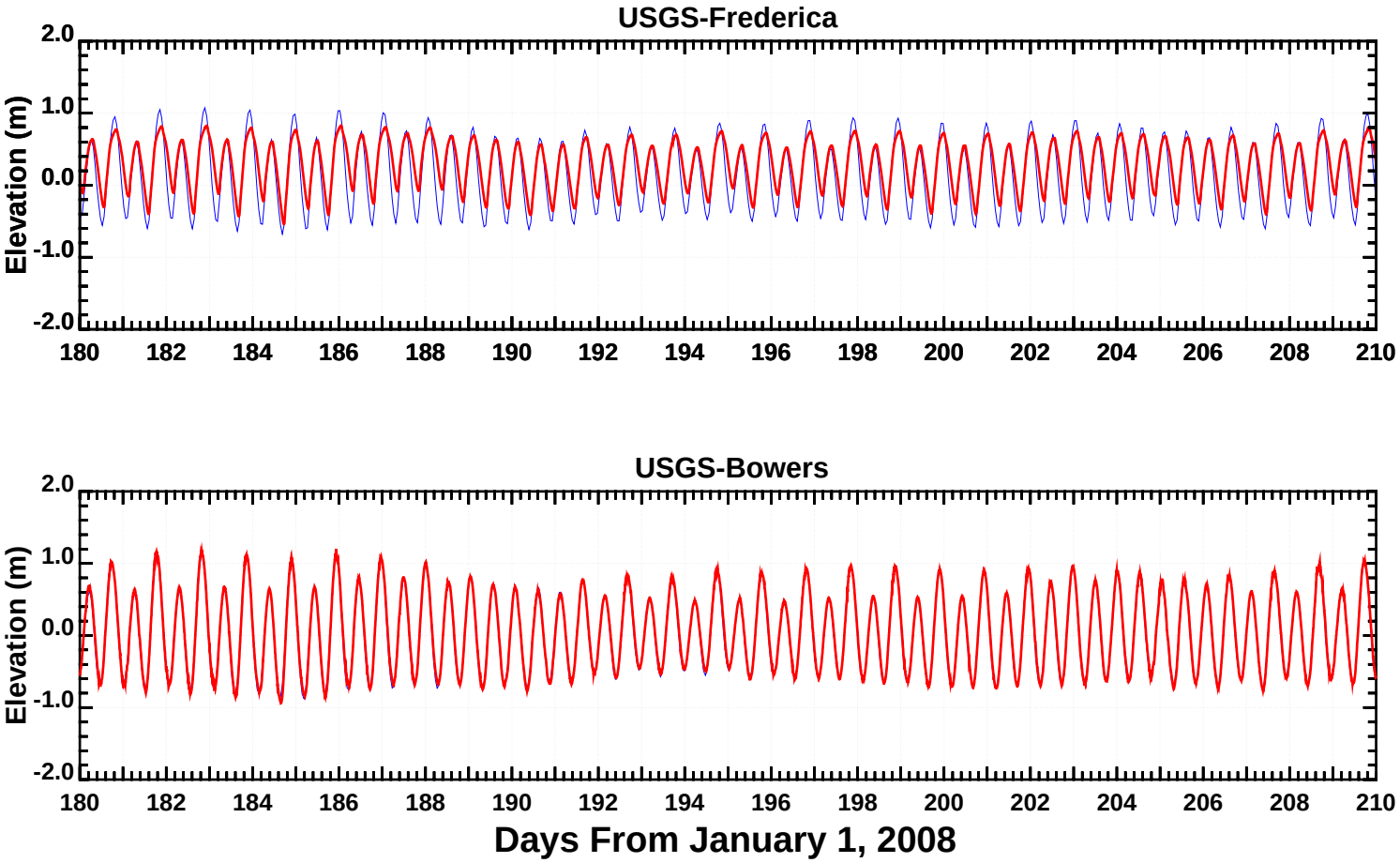

DNREC Study
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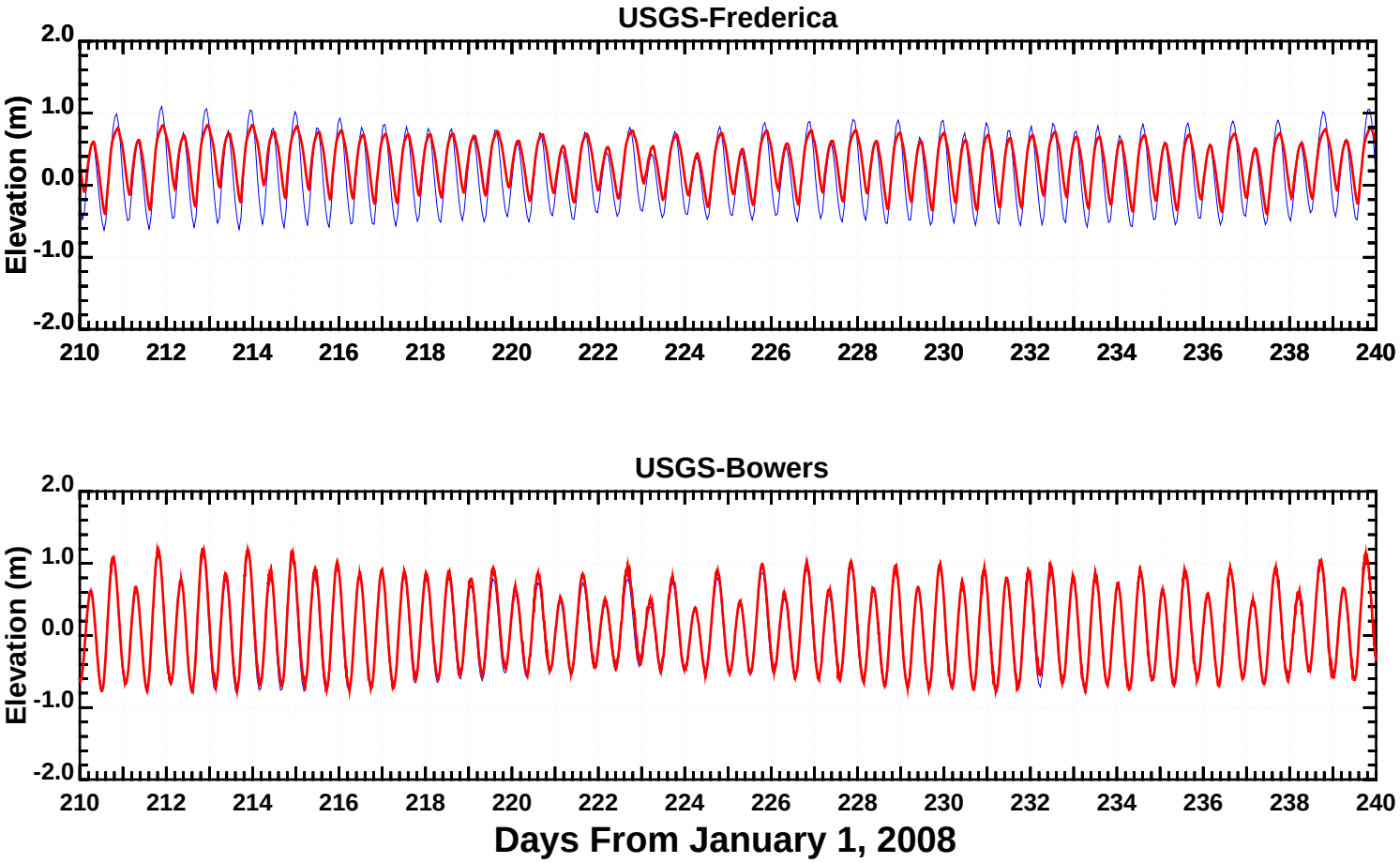

DNREC Study
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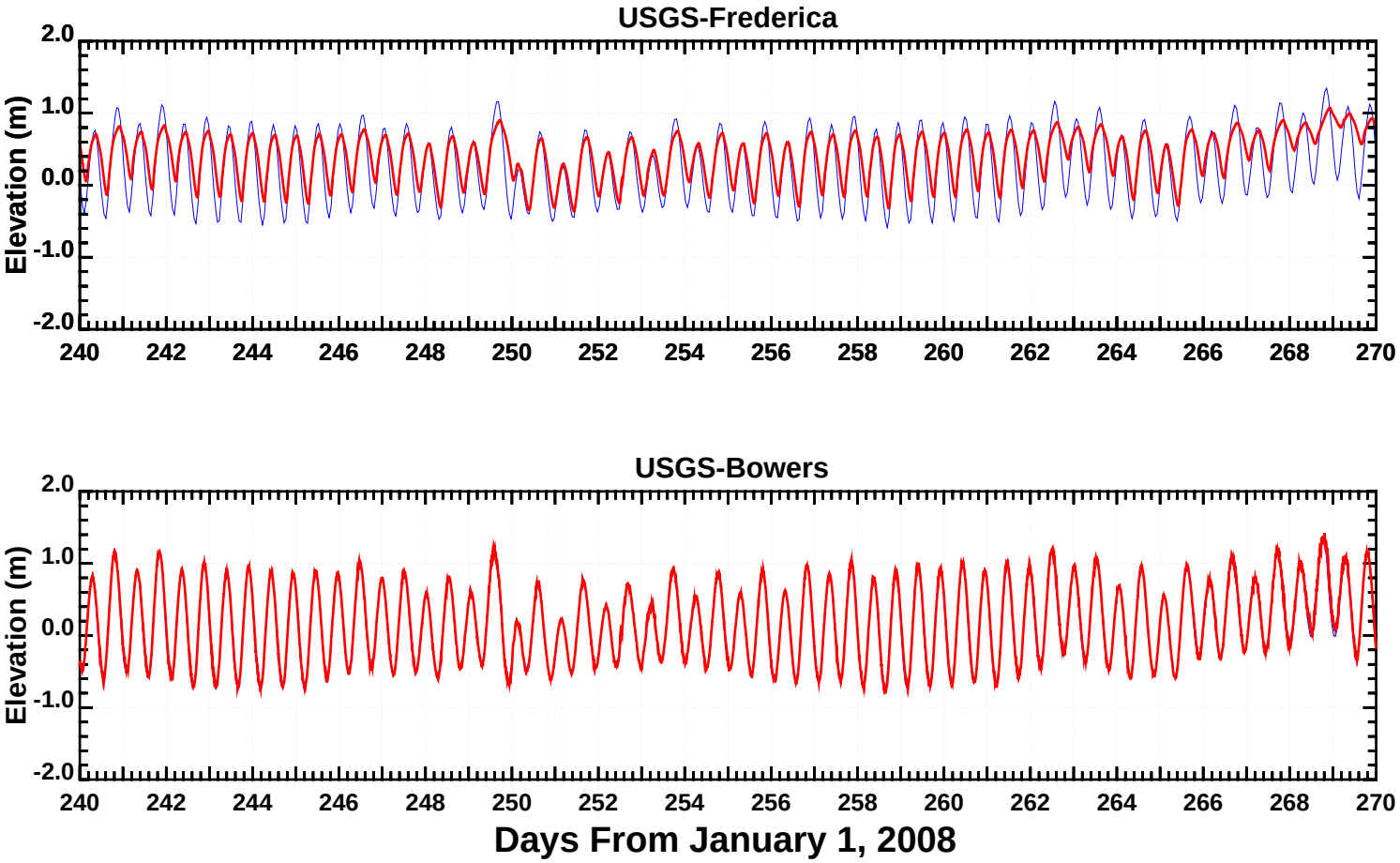

DNREC Study
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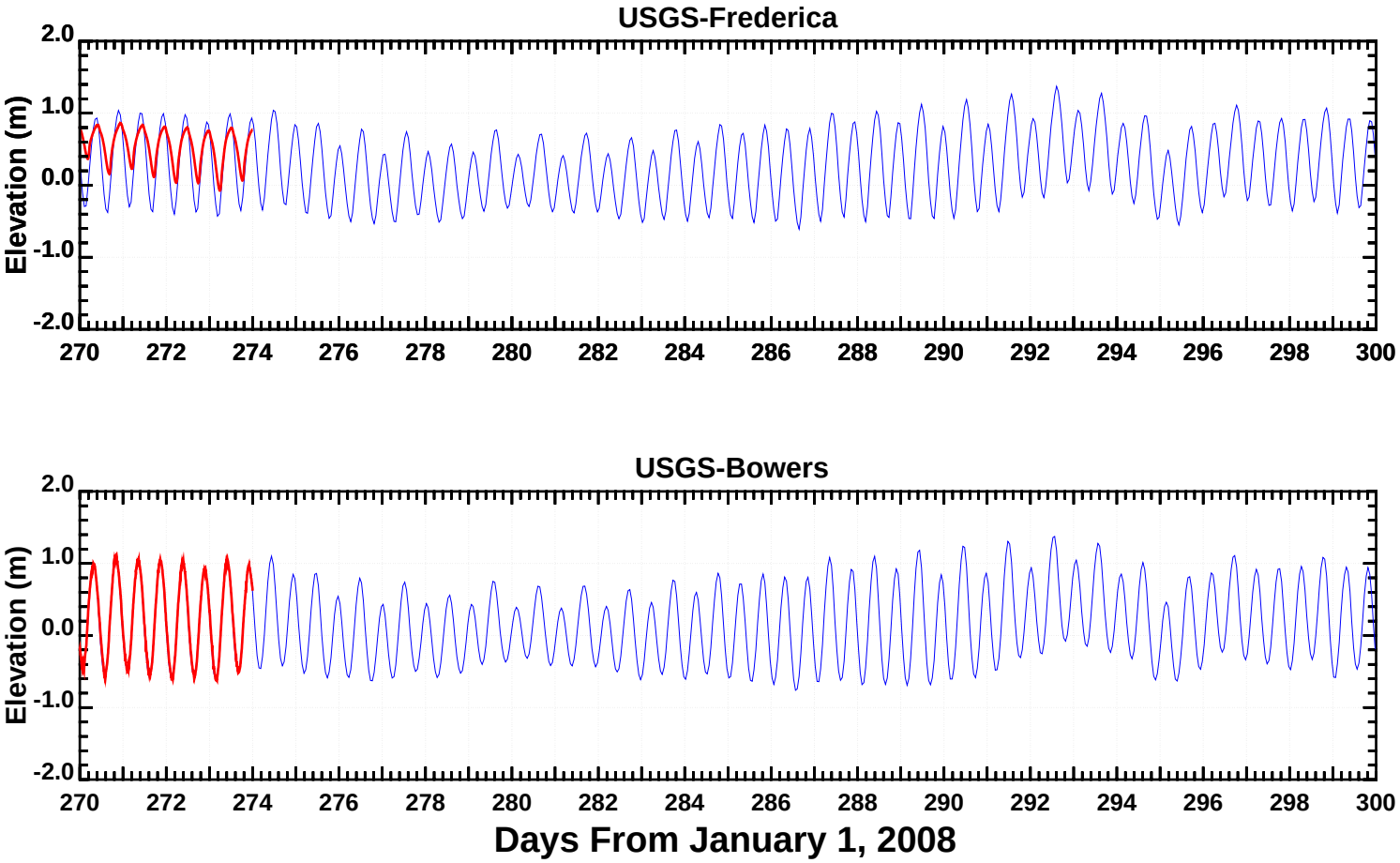

DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

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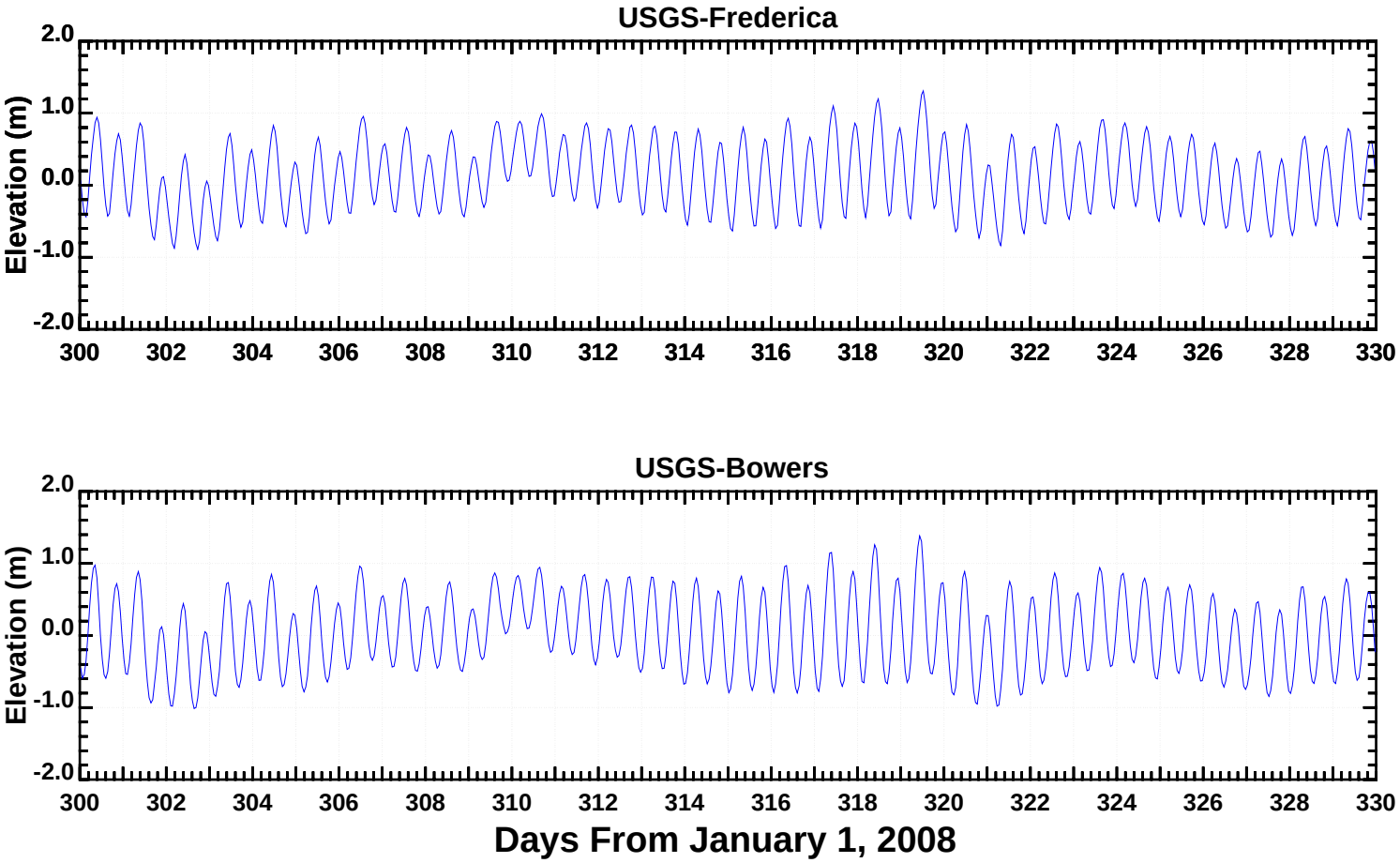
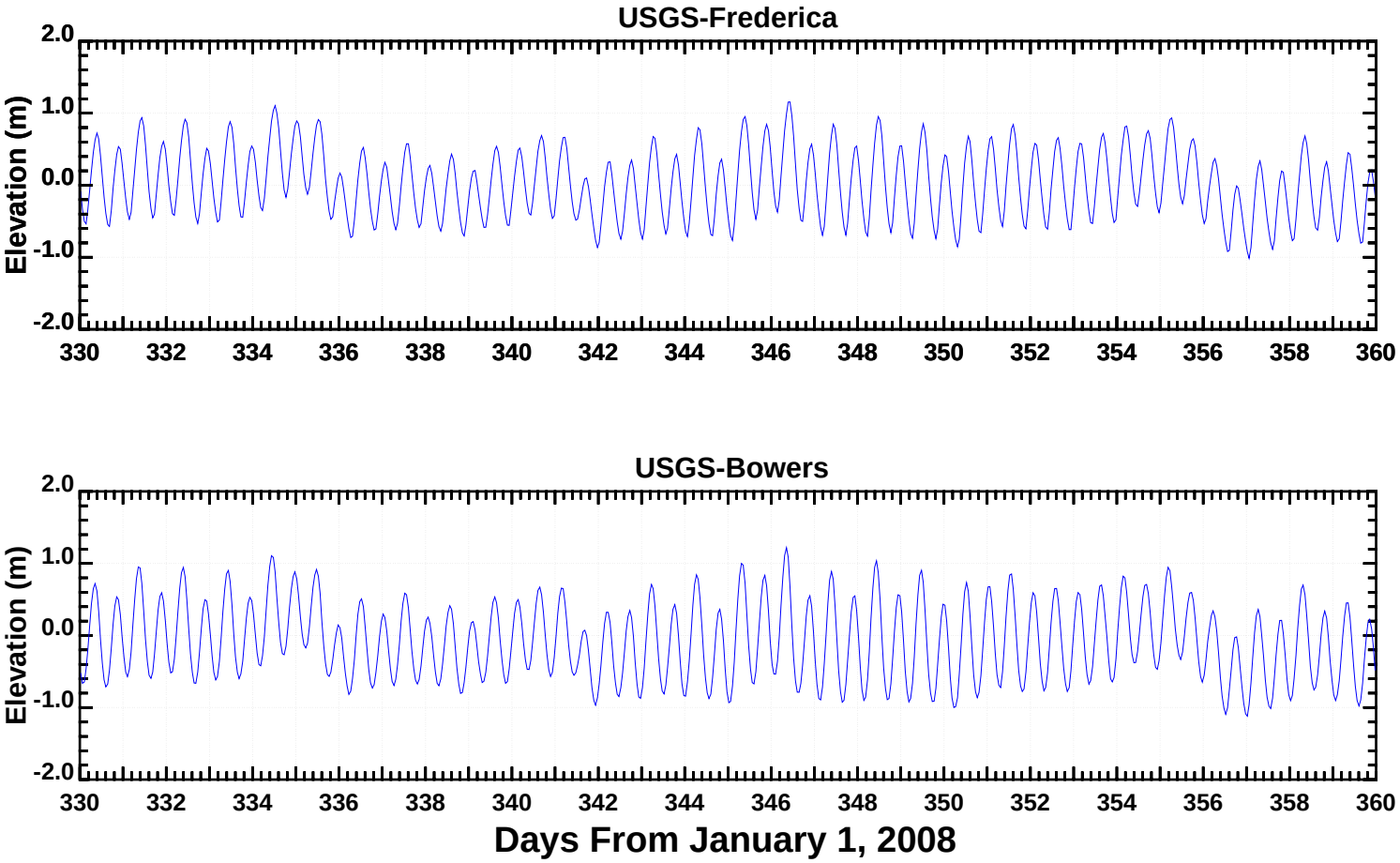


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

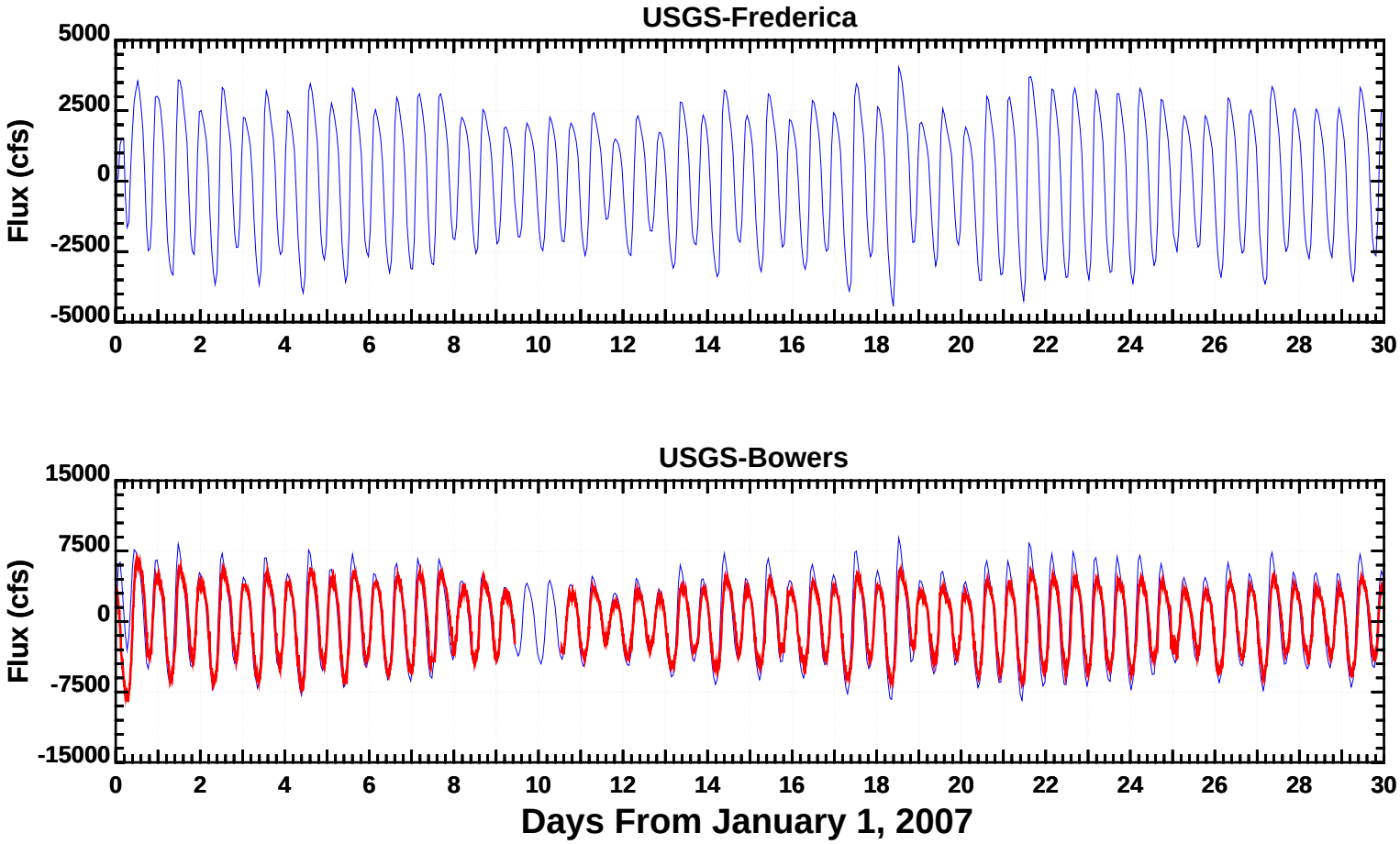


DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/ELEV/elevReport.gdp

08RUN003: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flows .

APPENDIX 6

HYDRODYNAMIC MODEL
TIDAL FLUX
CALIBRATION/VALIDATION
FIGURES



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

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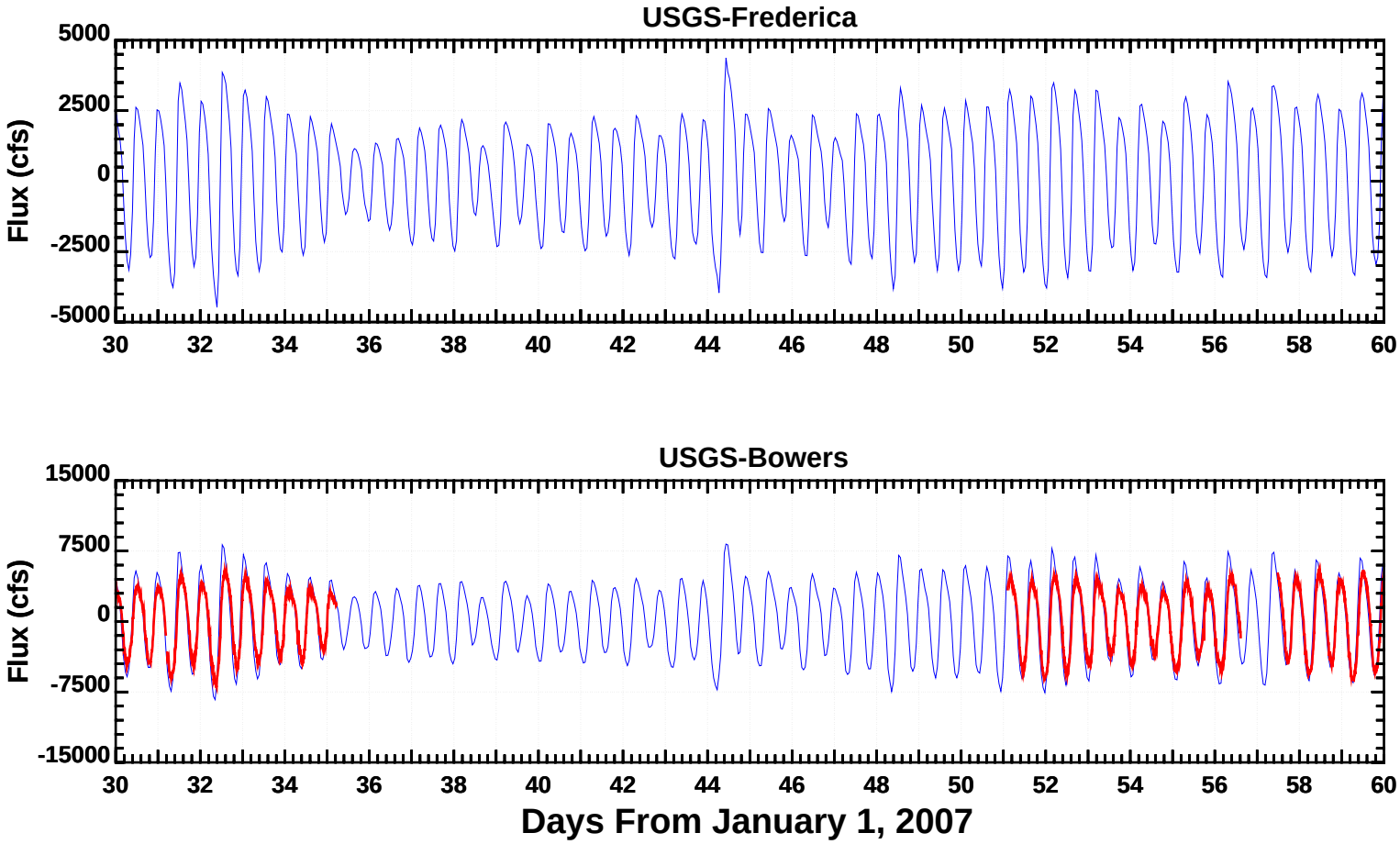
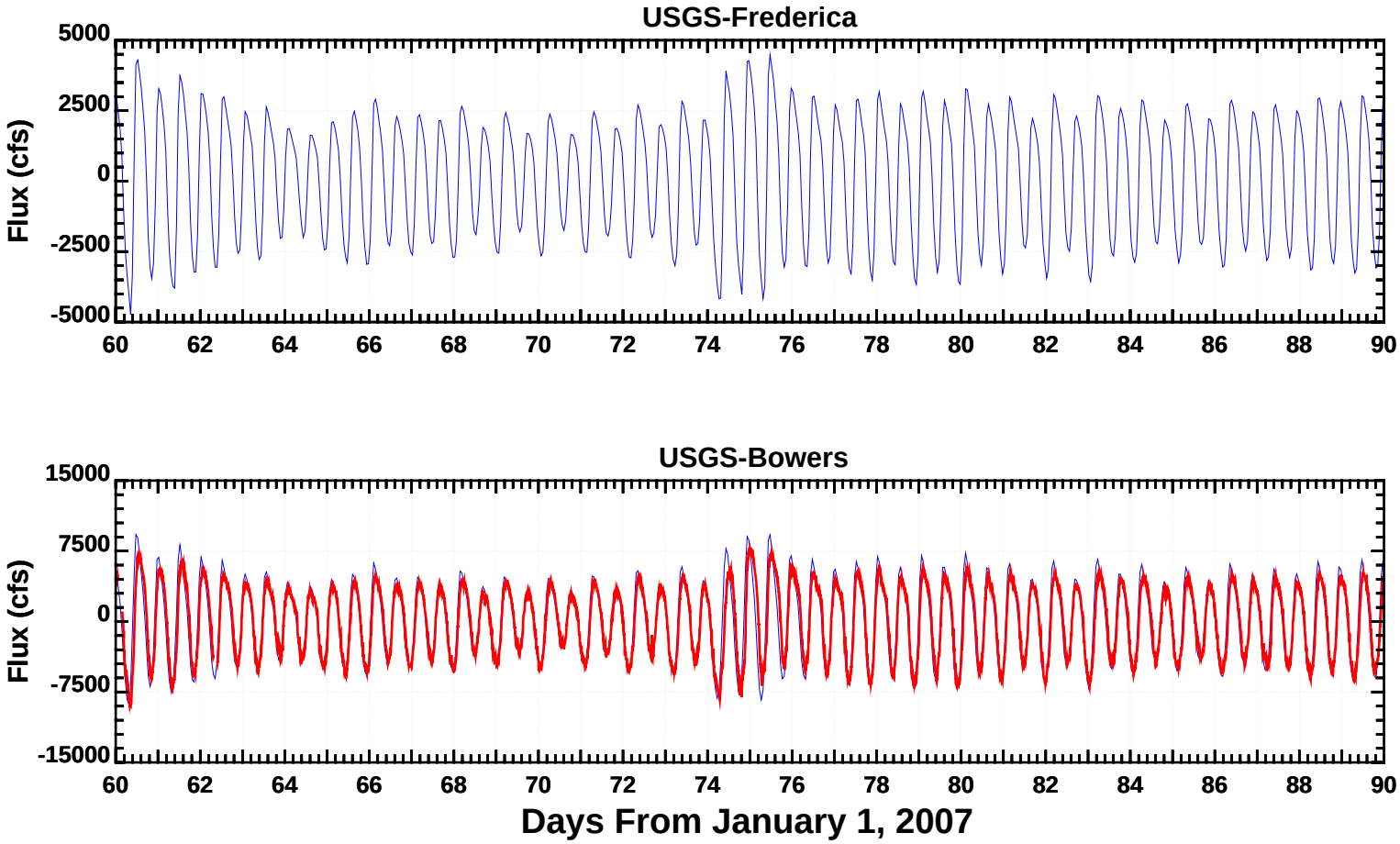
DATE: 1/22/2013 TIME: 1:22:29



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

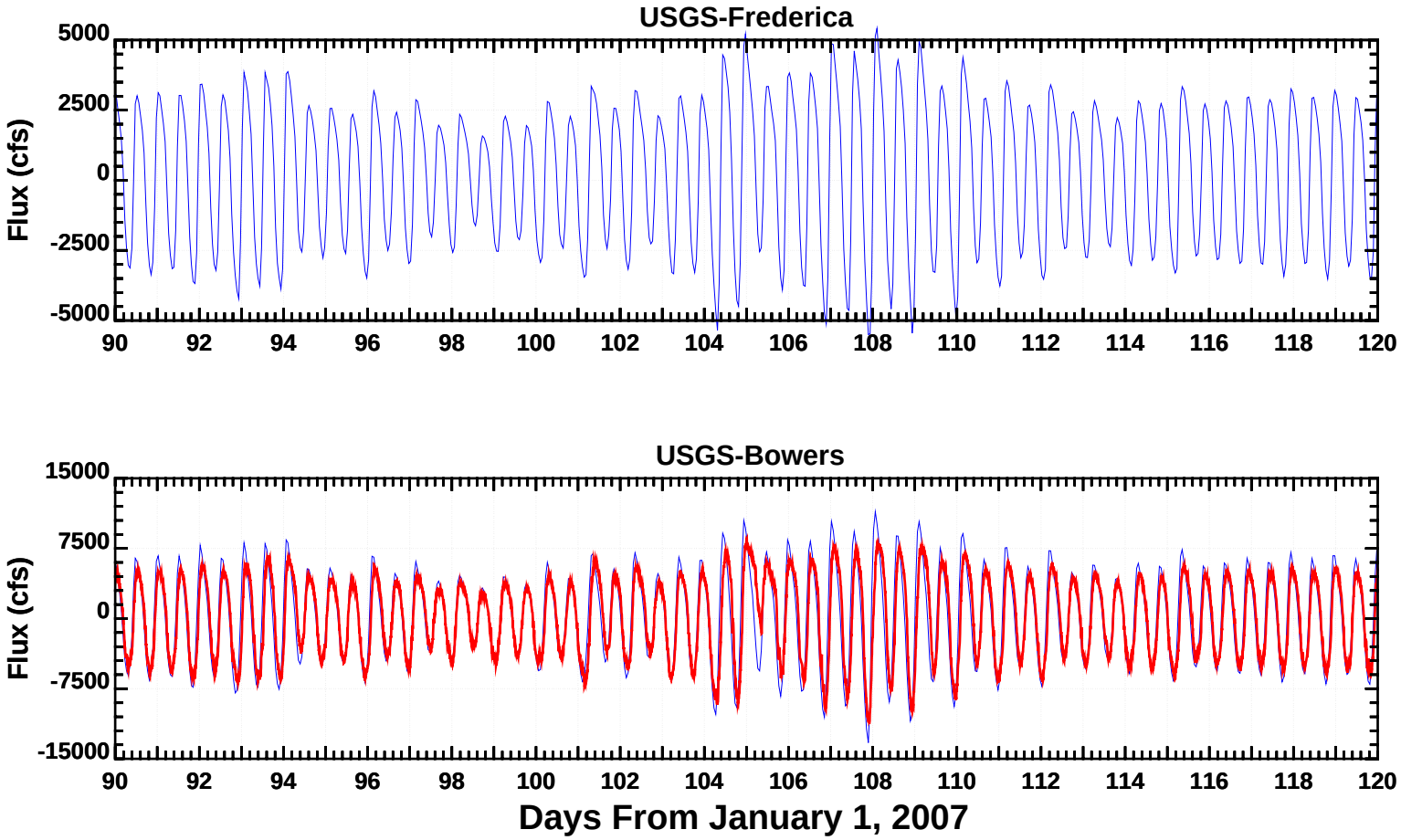
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

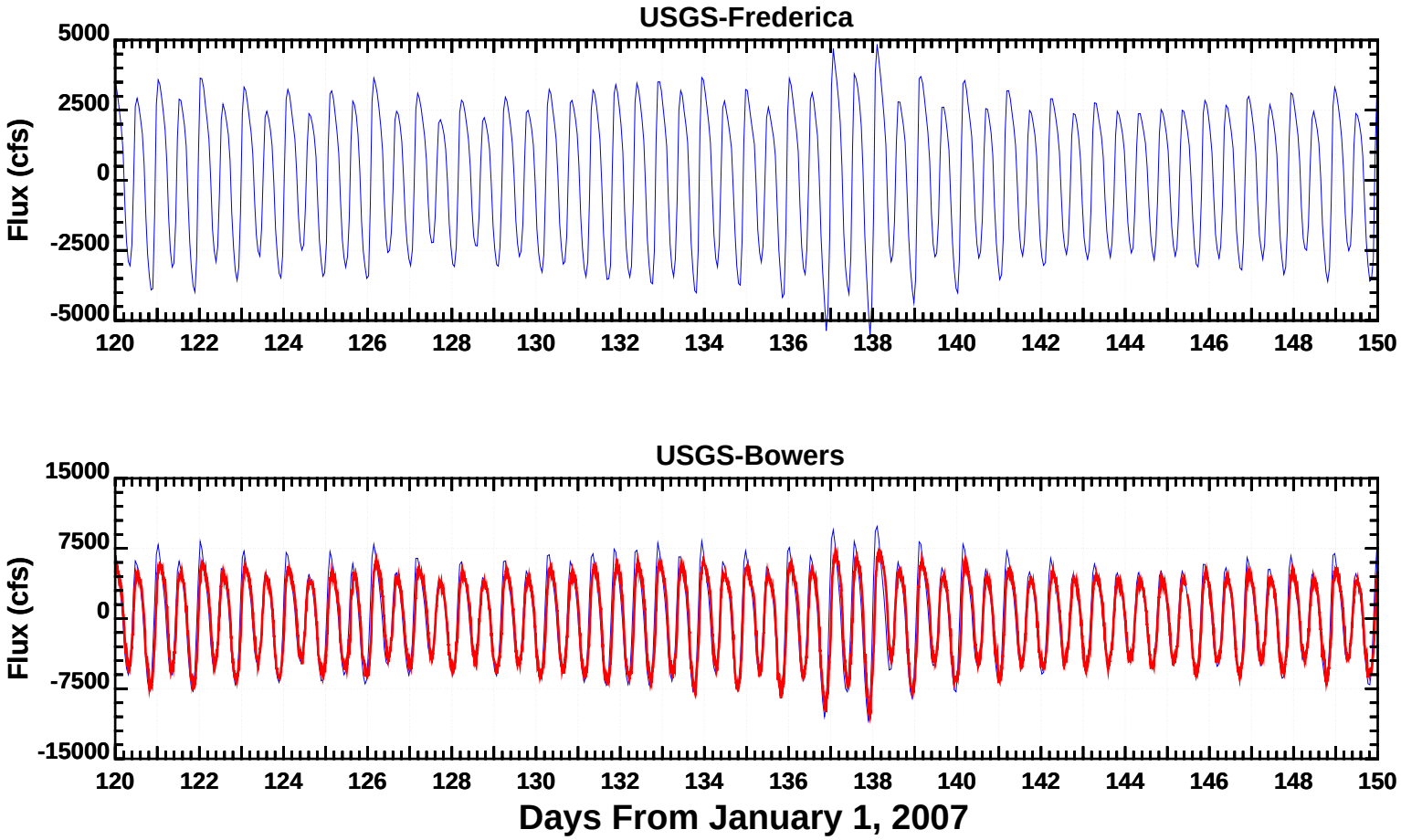
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 1:22:40



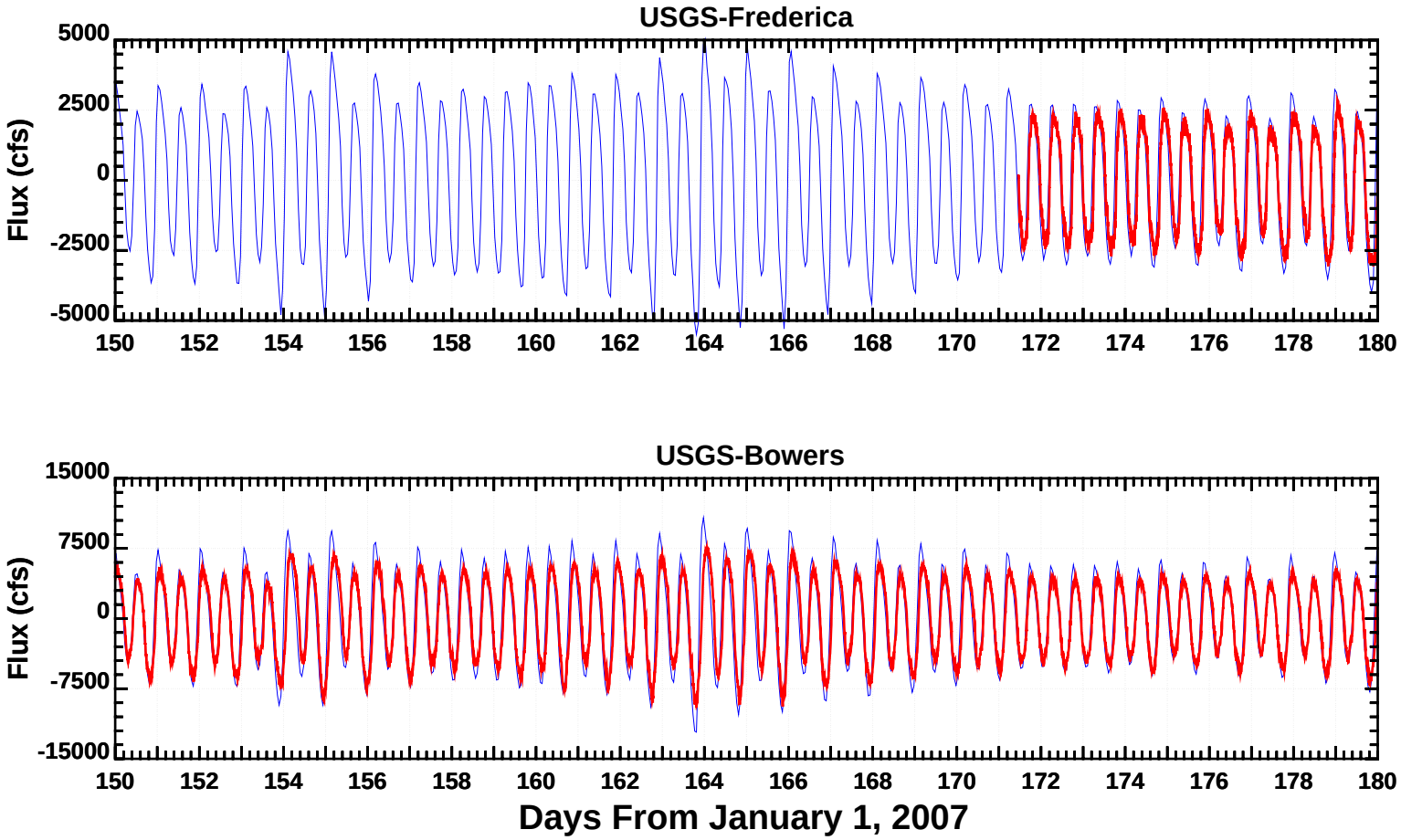
DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

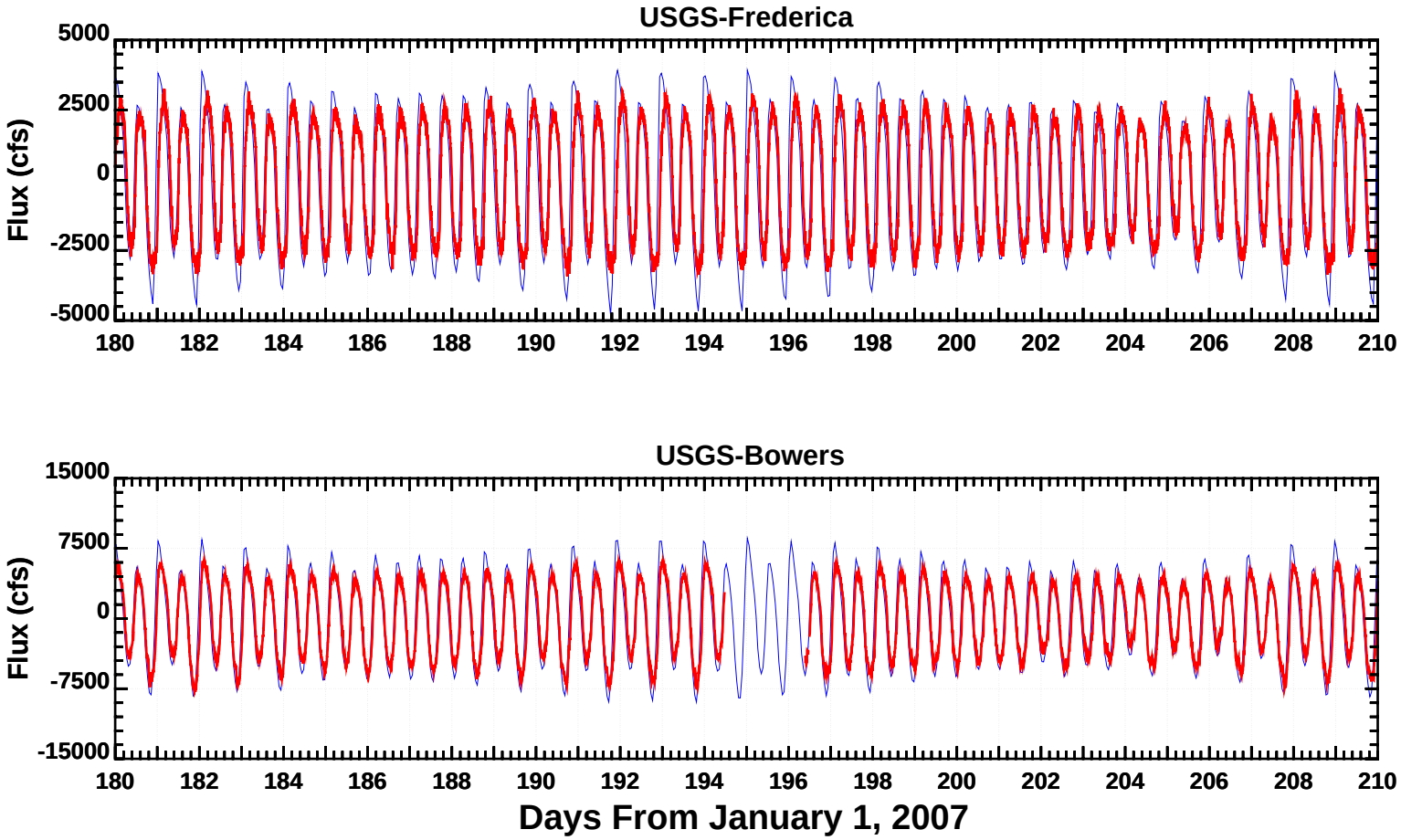
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

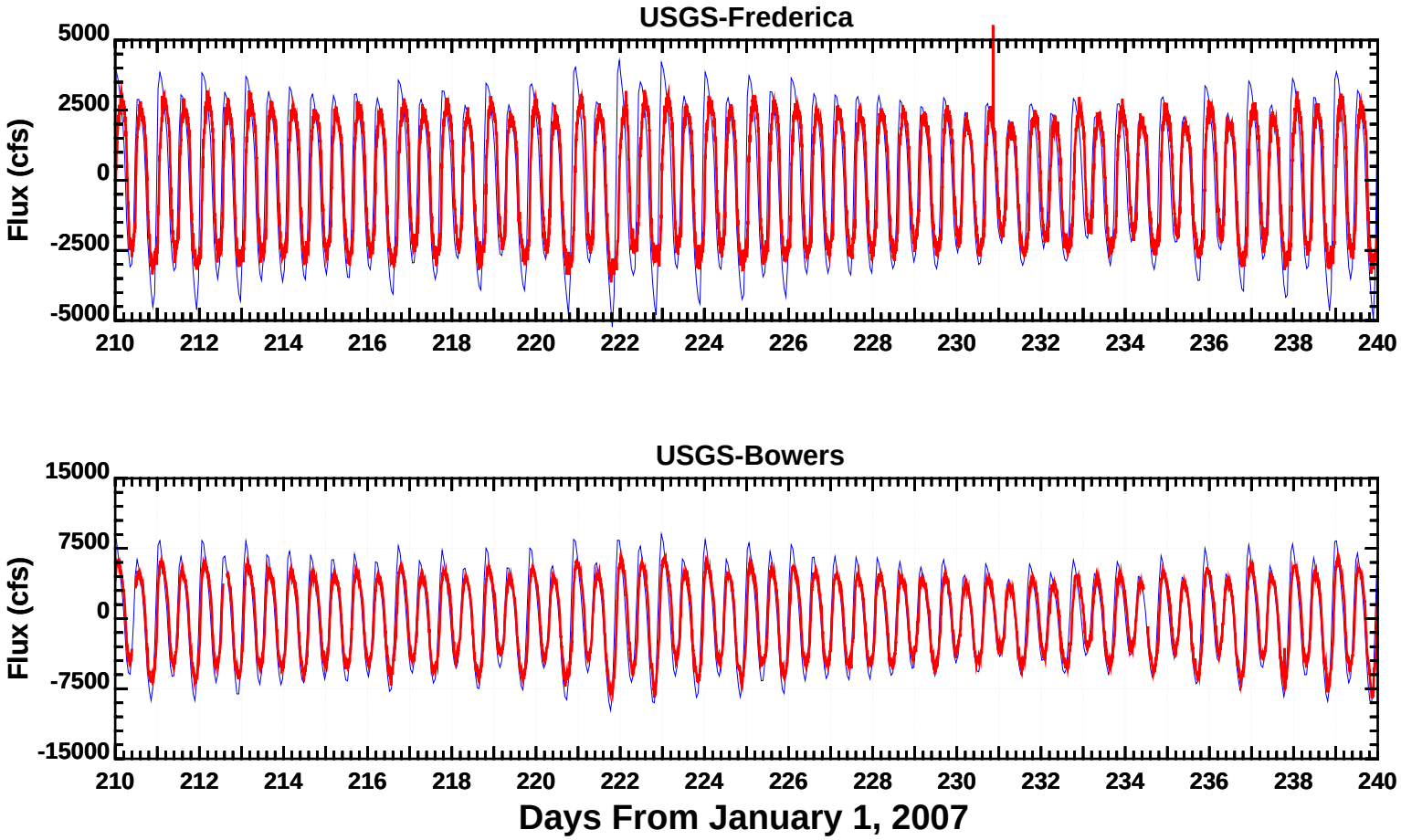
RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .

DATE: 1/22/2013 TIME: 1:22:59



DNREC Study
/birch1/kcdw0014/HYDRO/PLOTS/FLUXES/fluxReport.gdp

RUN031: 010708*v18.thindams,defaultBFRIC,HORCONx0.1, BowersDailyAvesalt-stratified-3,New100% flowp .



DNREC Study
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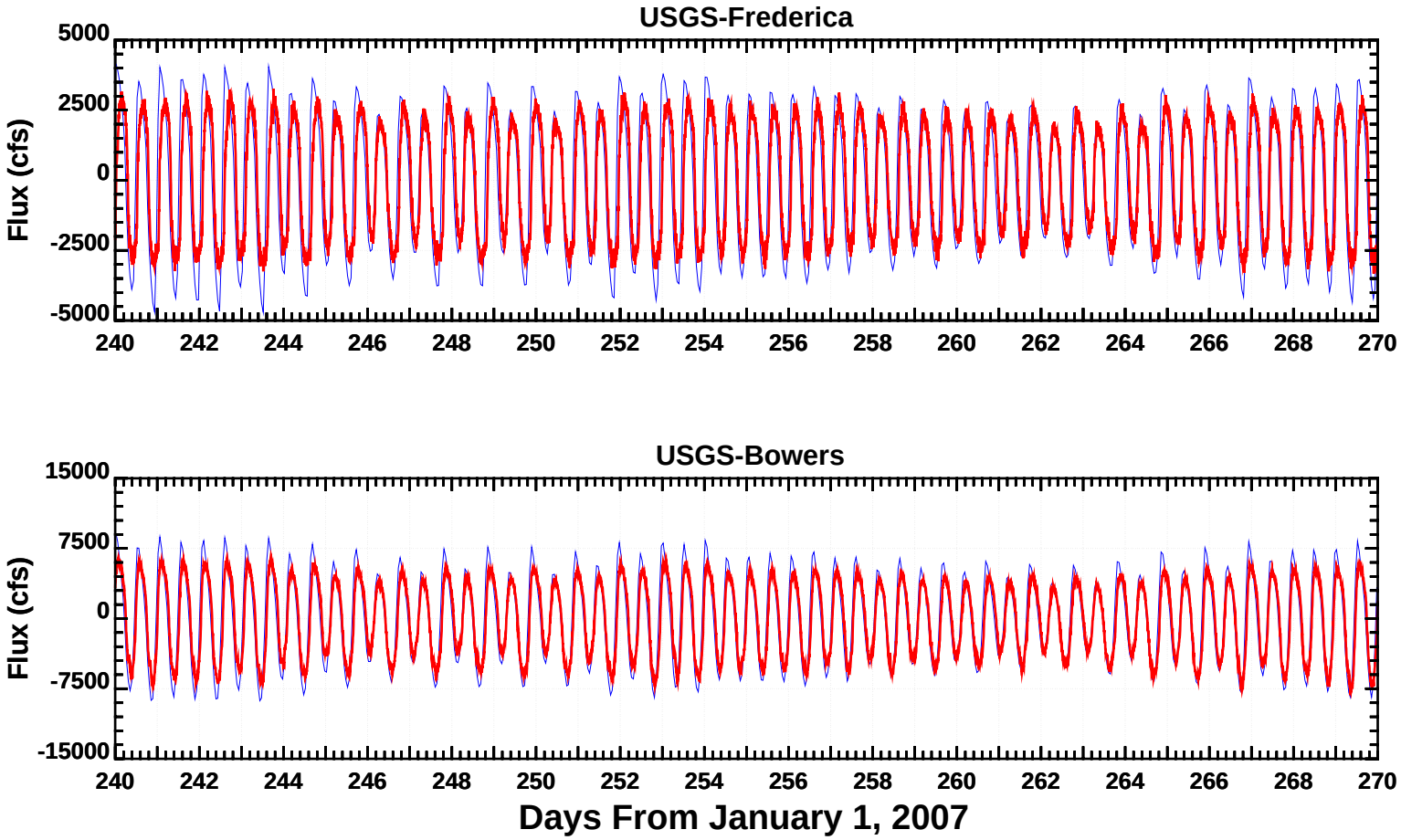

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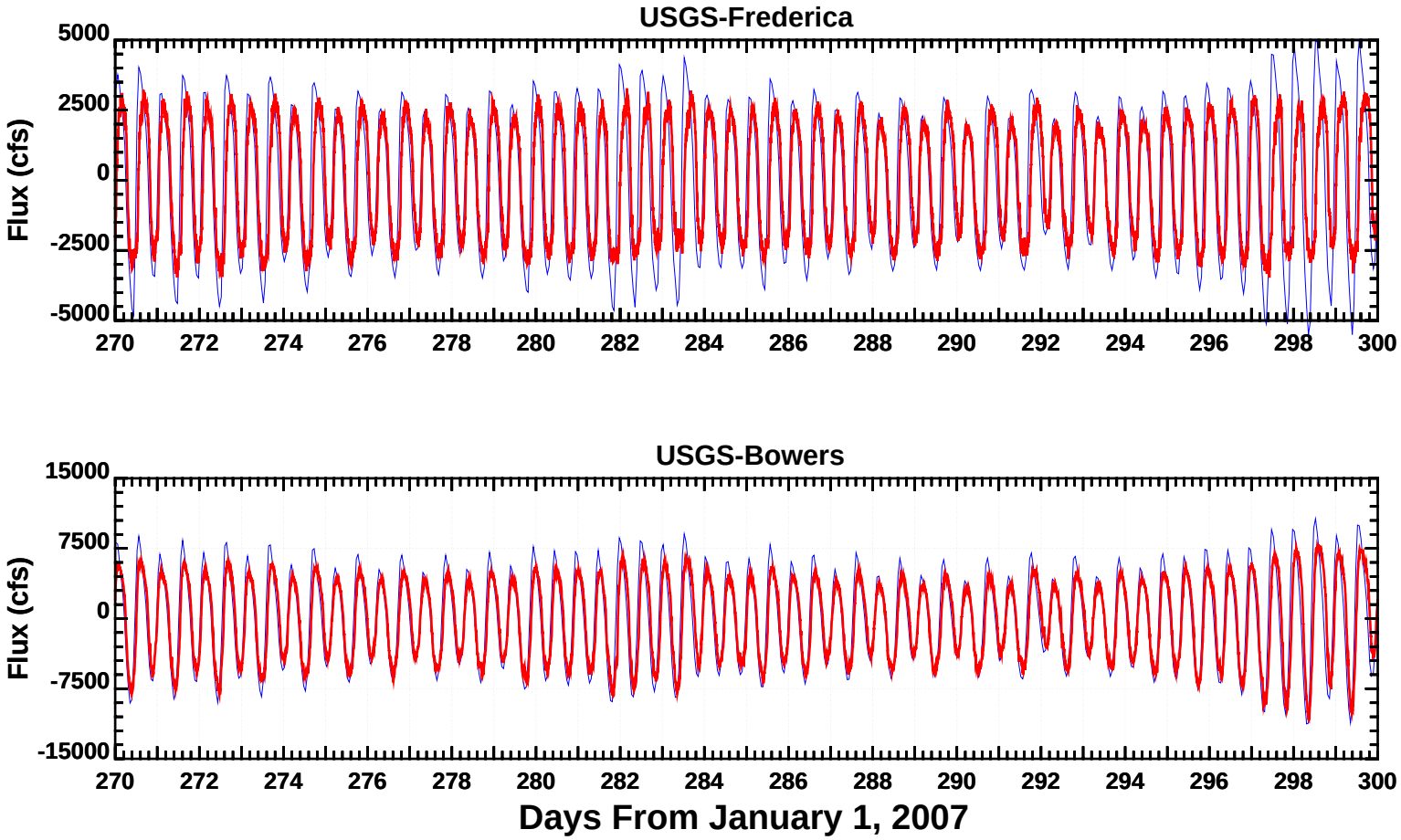

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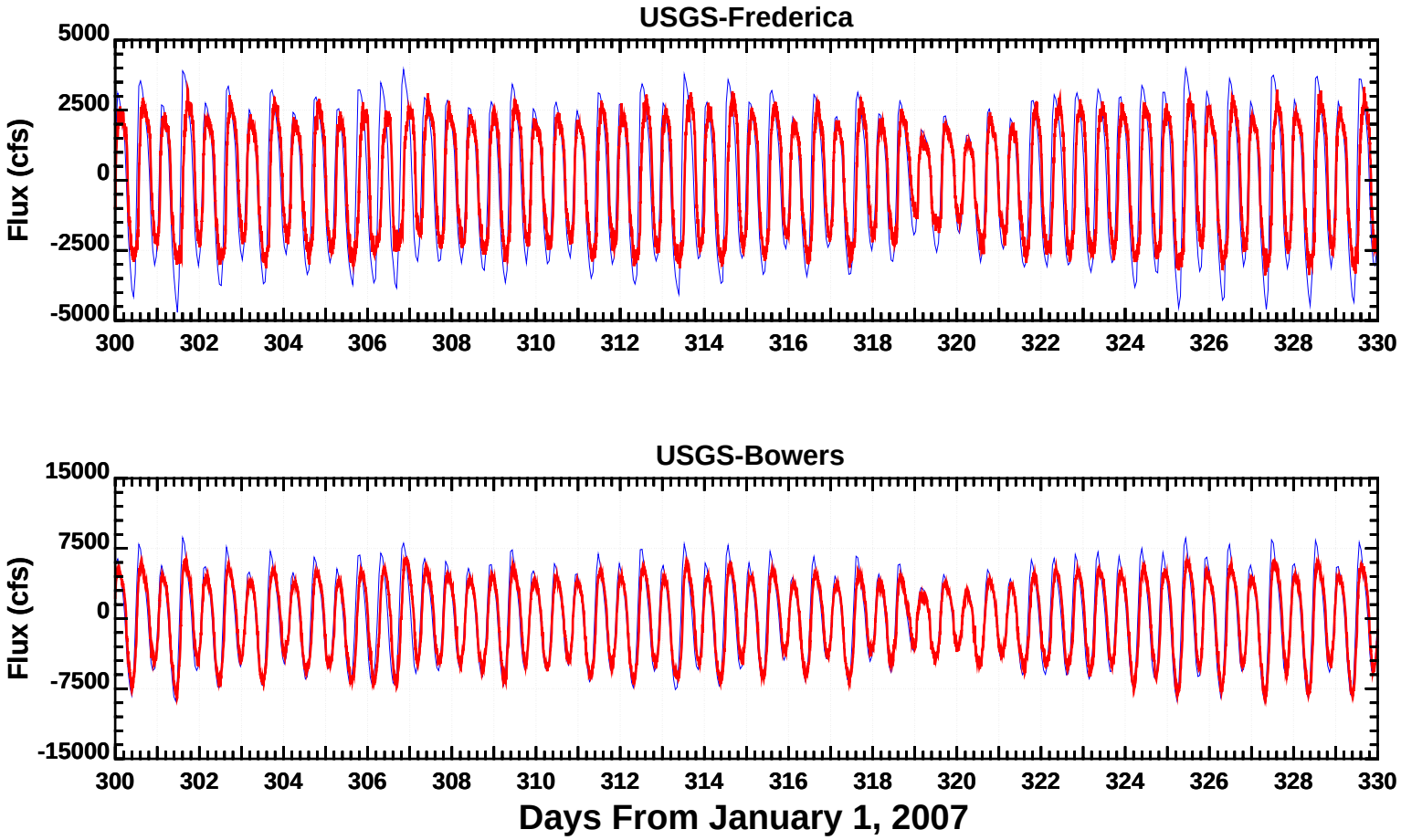

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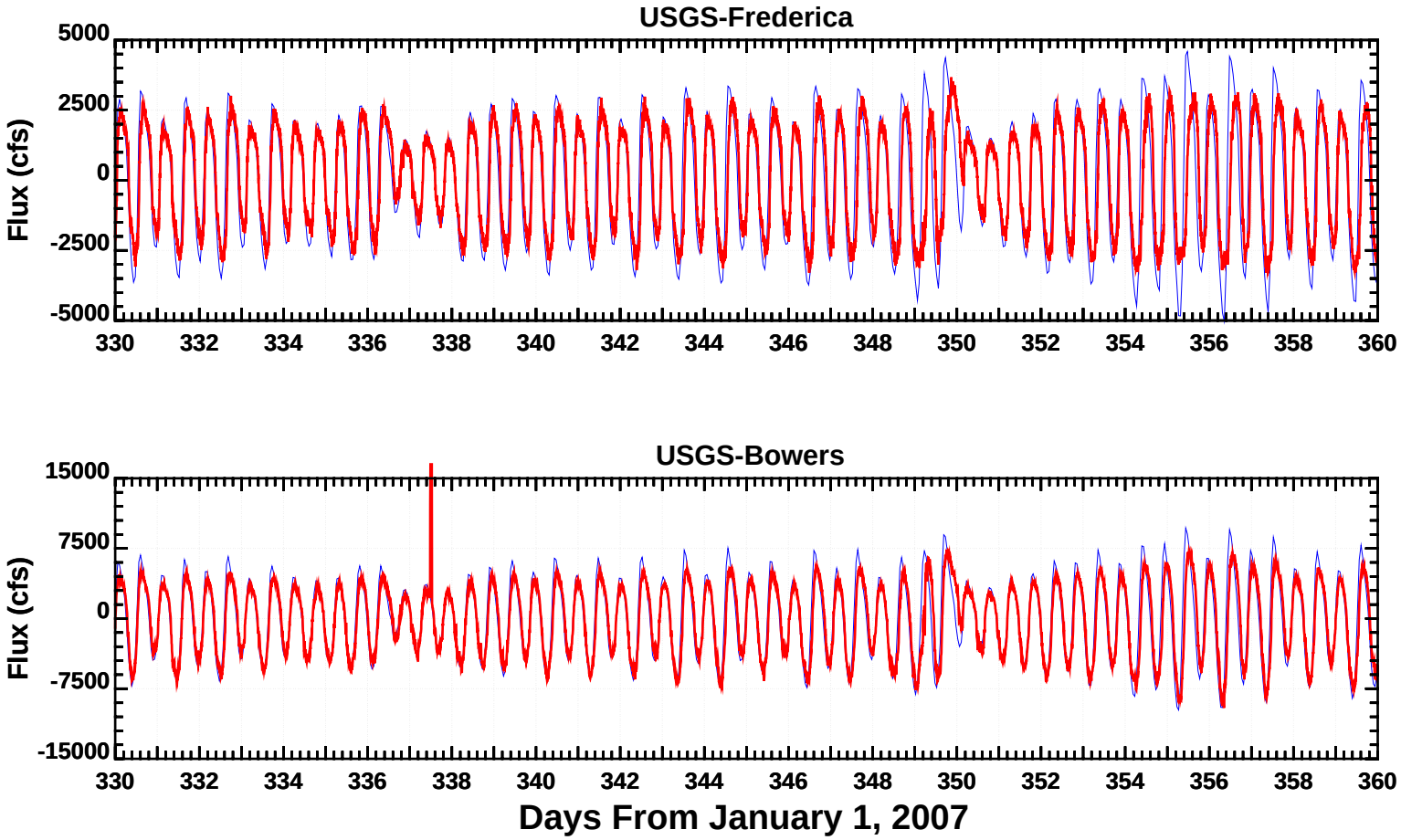

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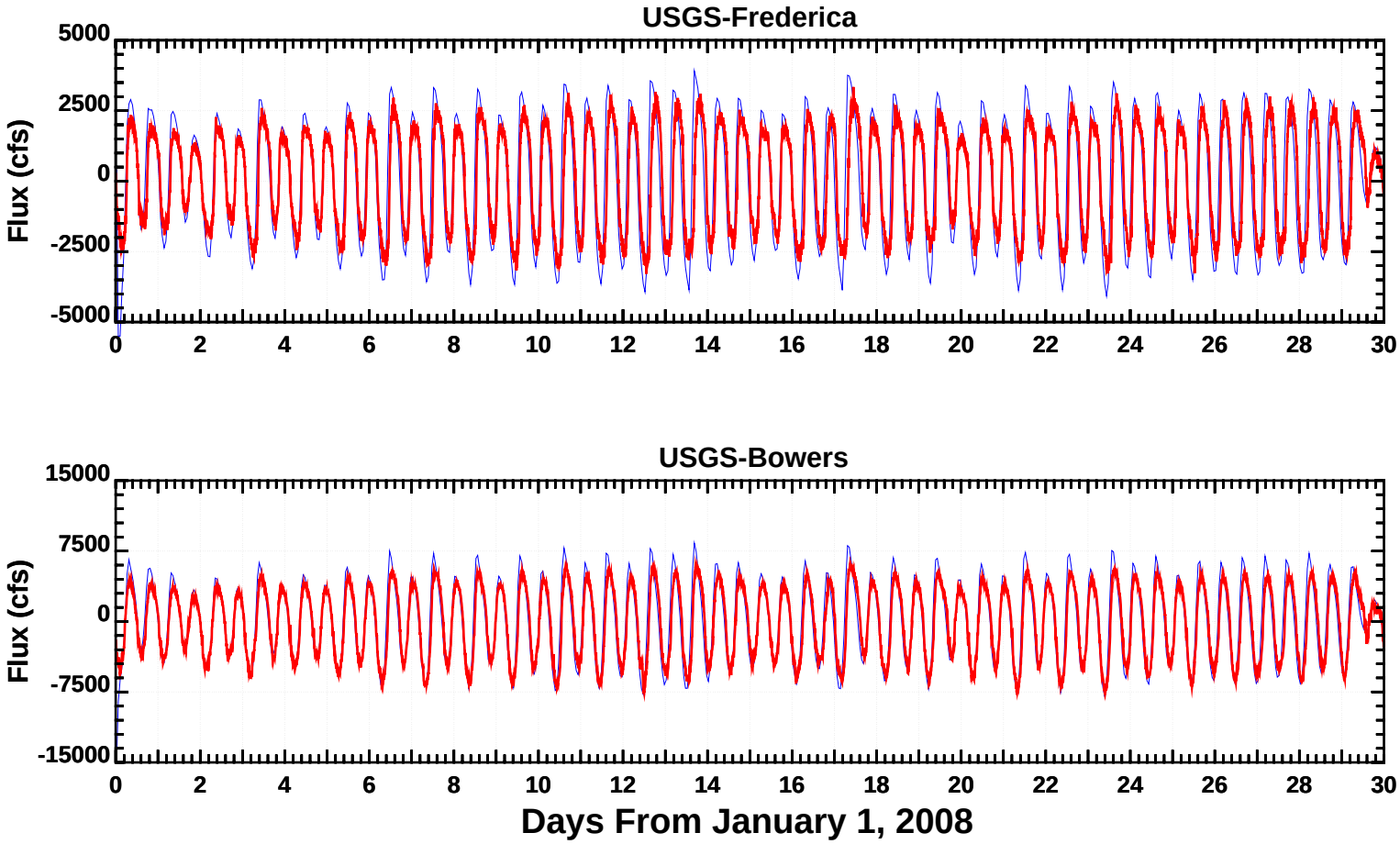

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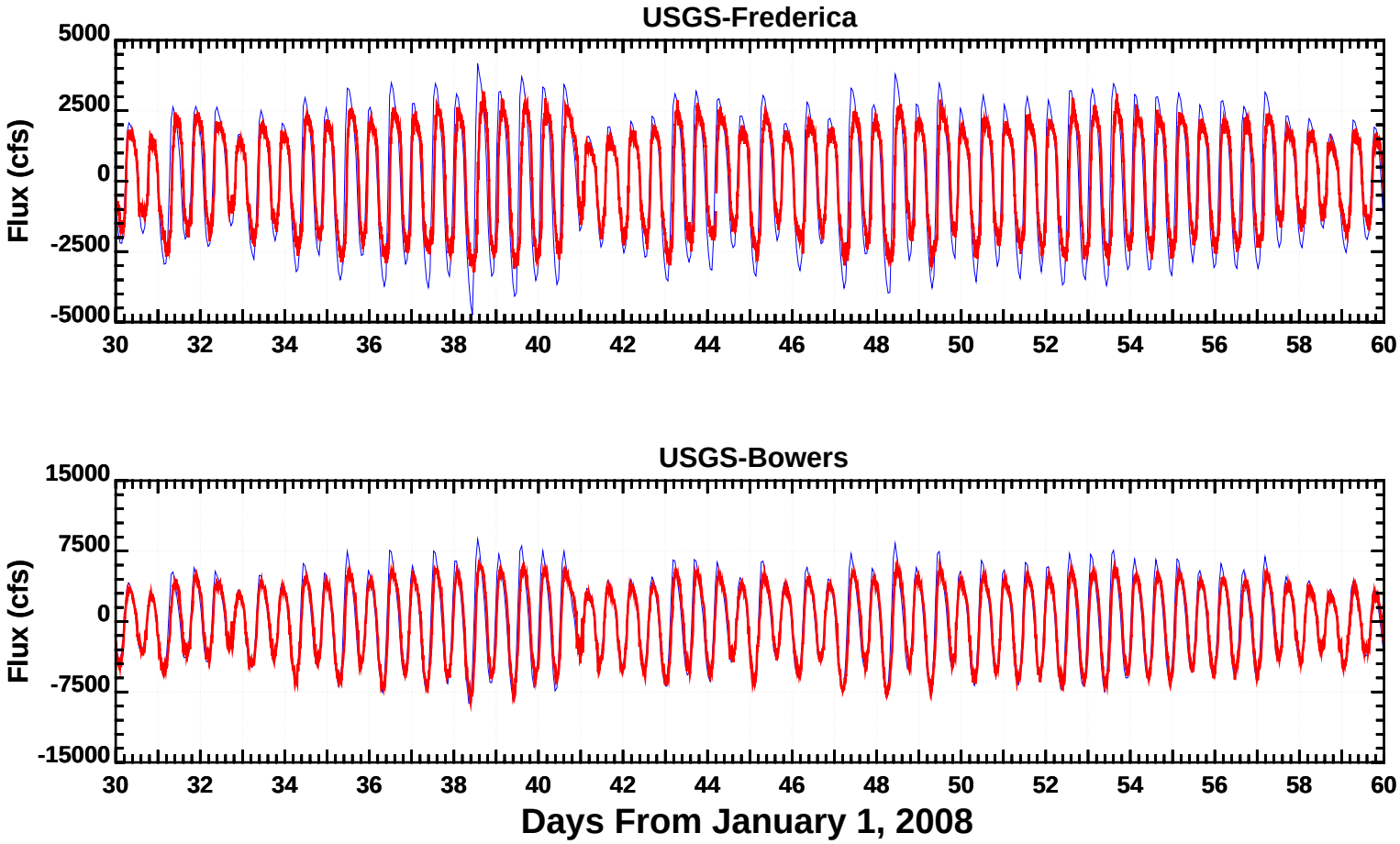

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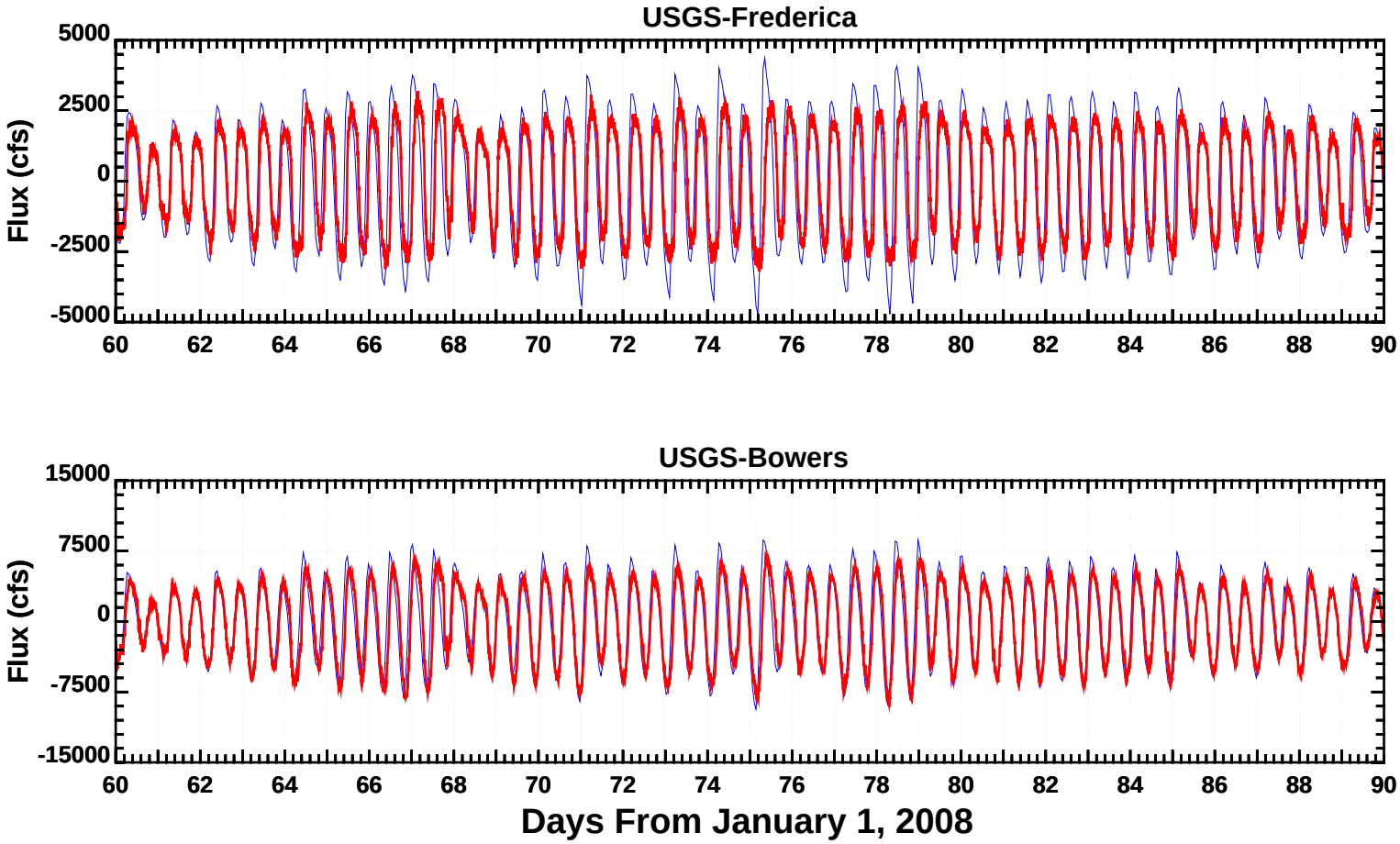

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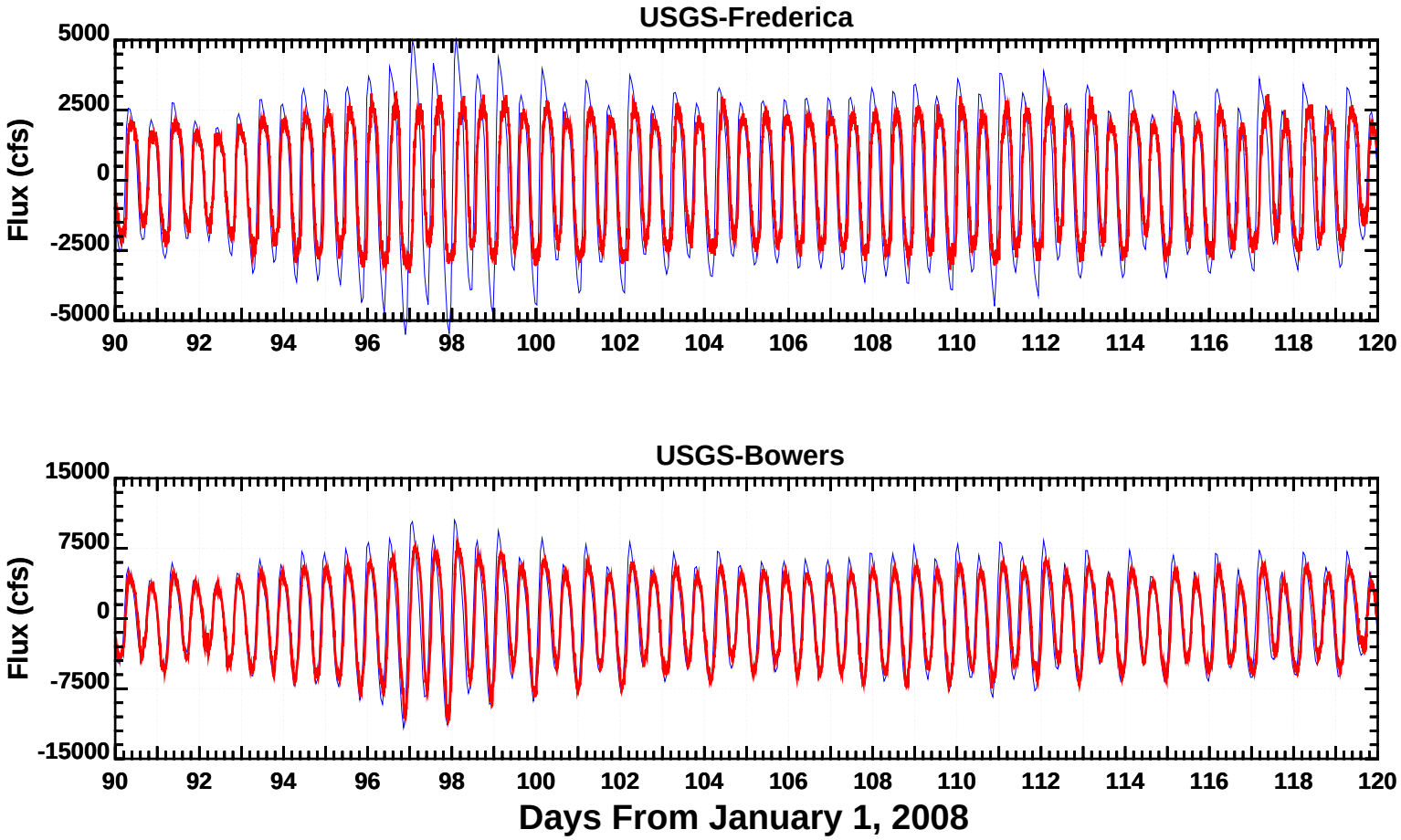

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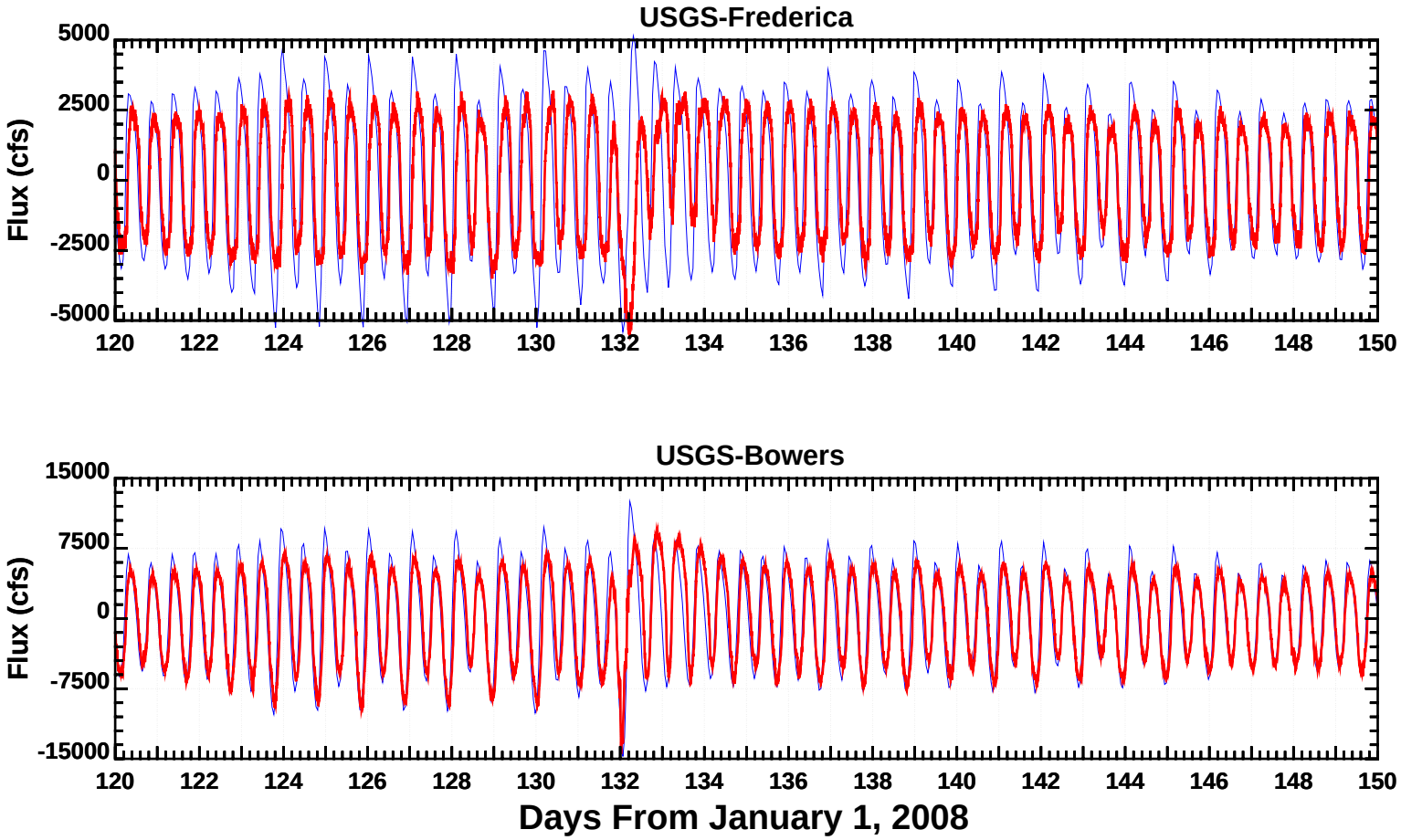

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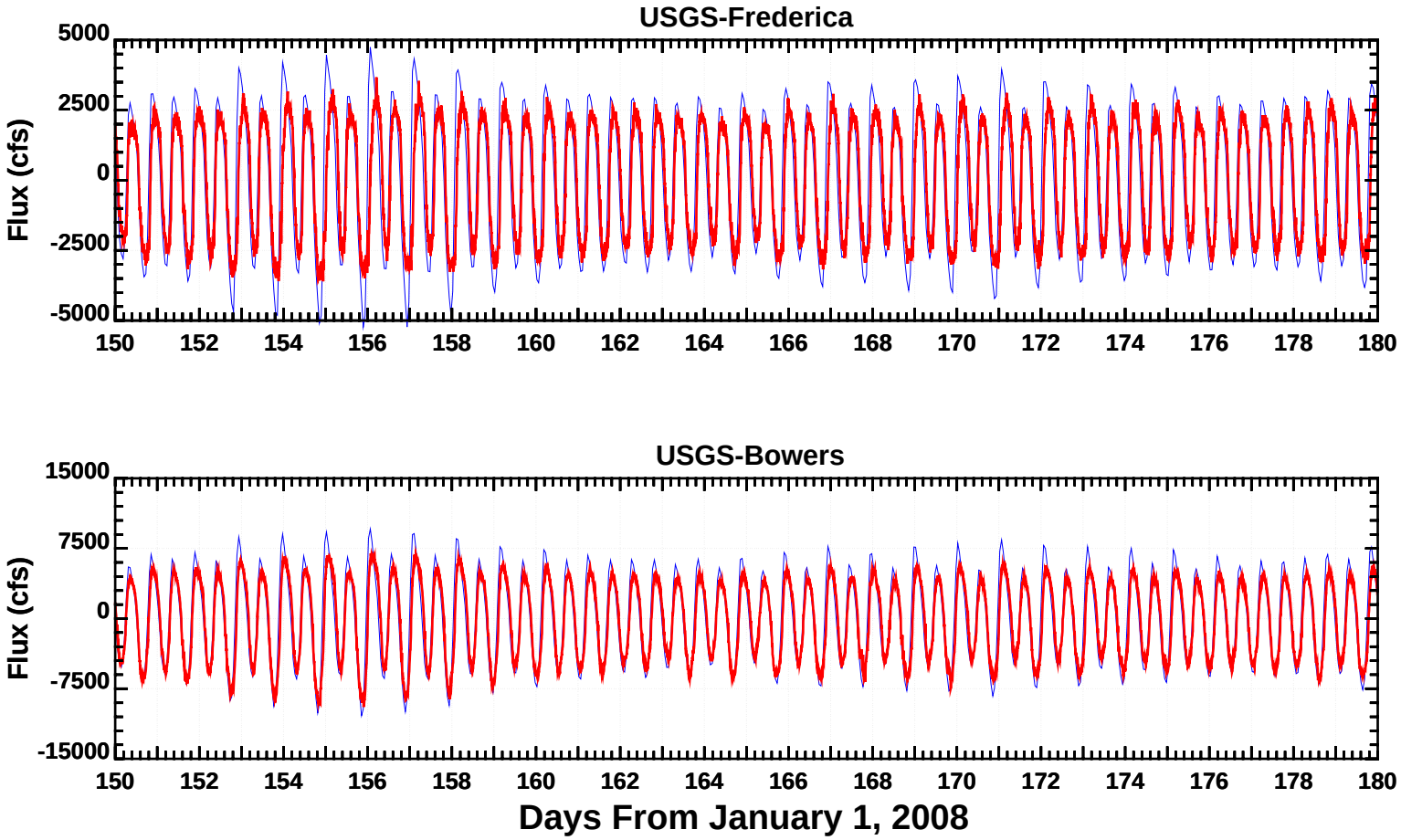

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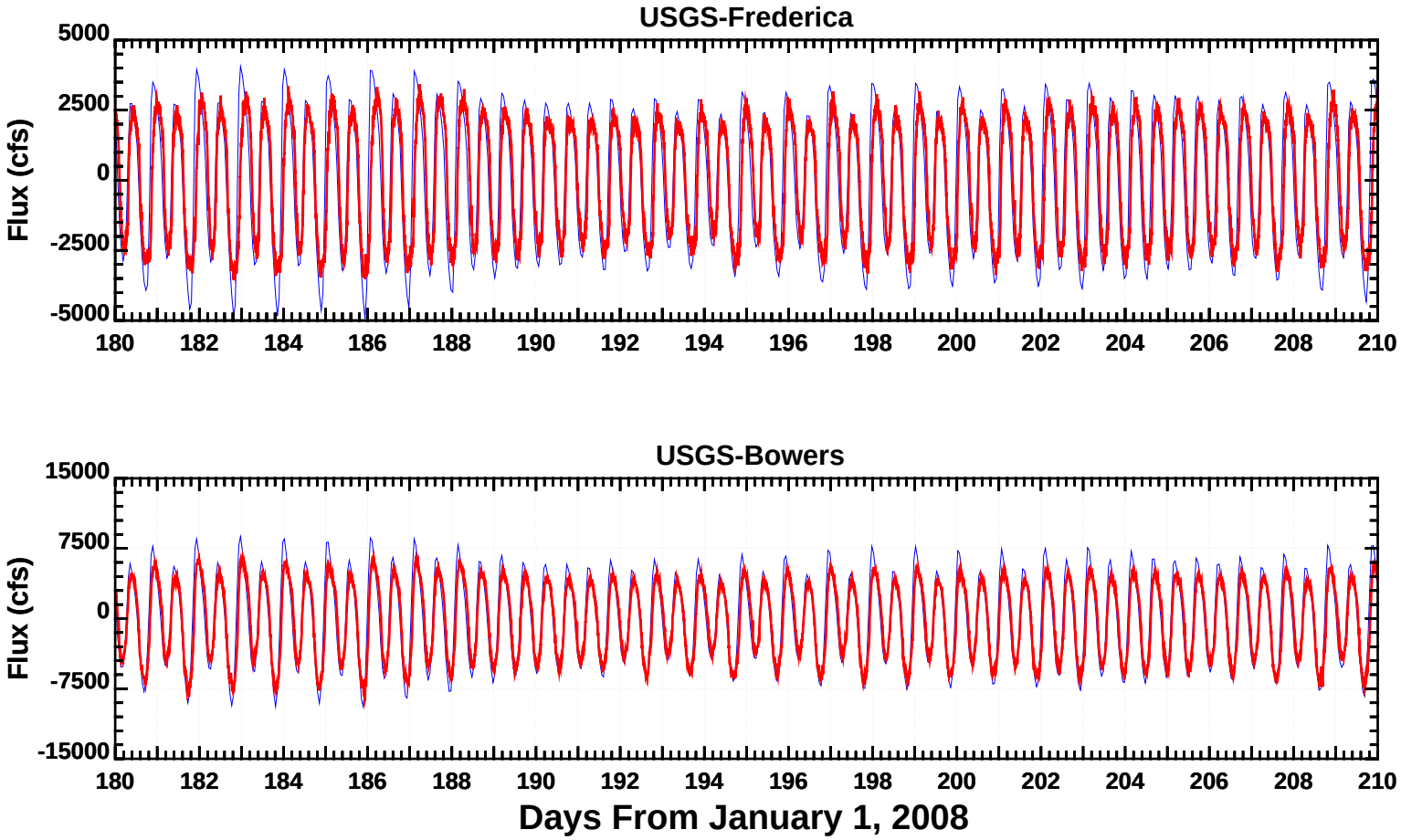

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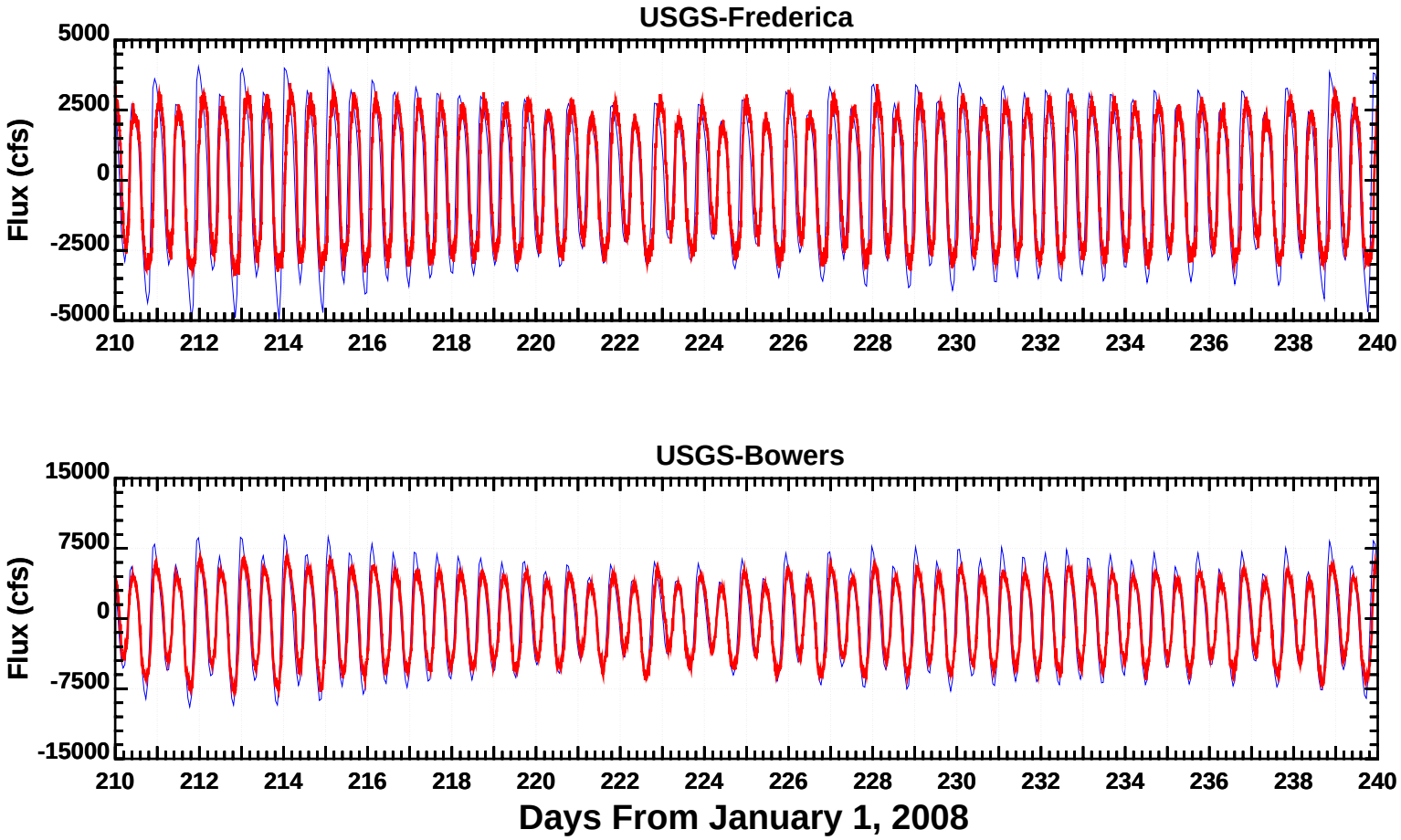

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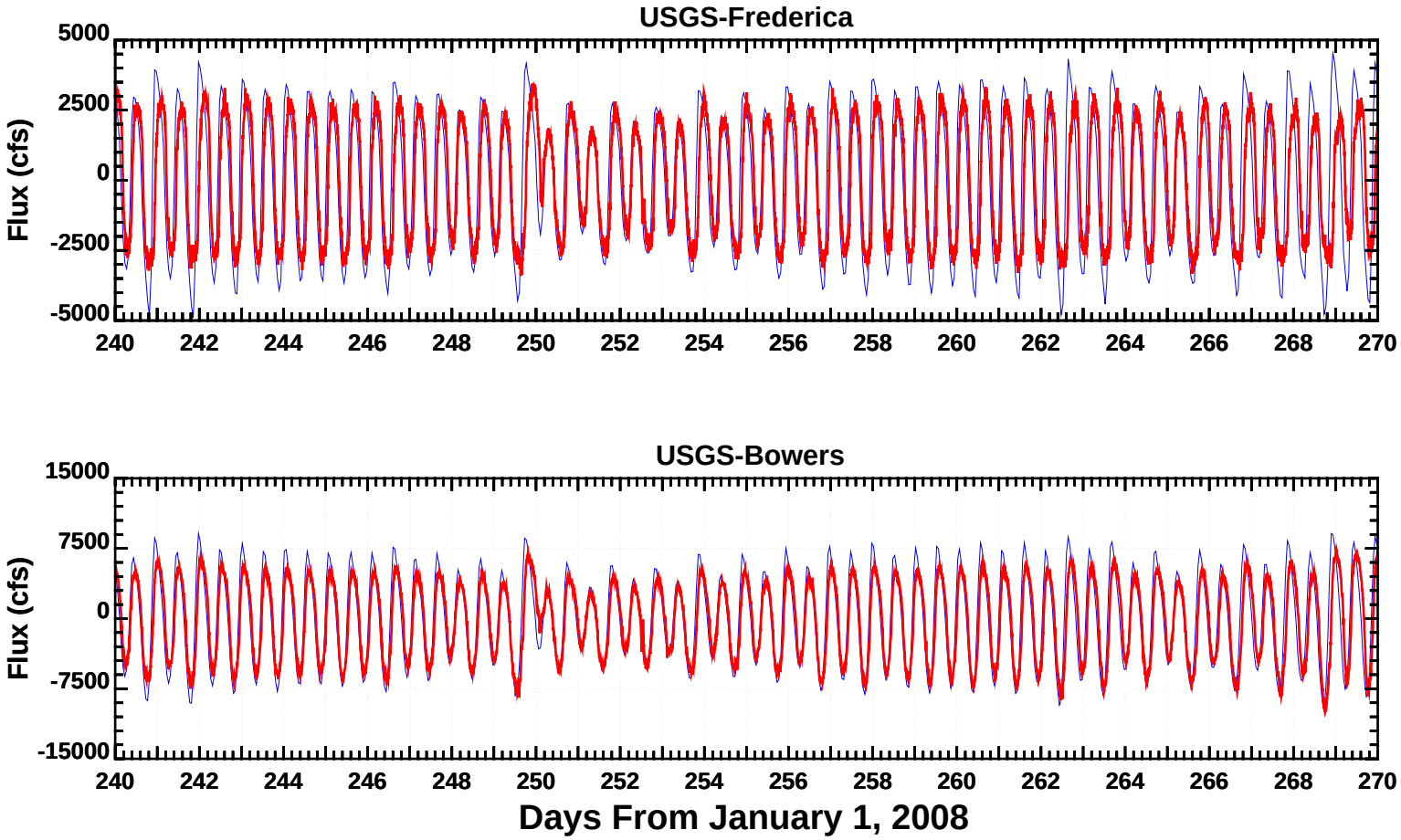

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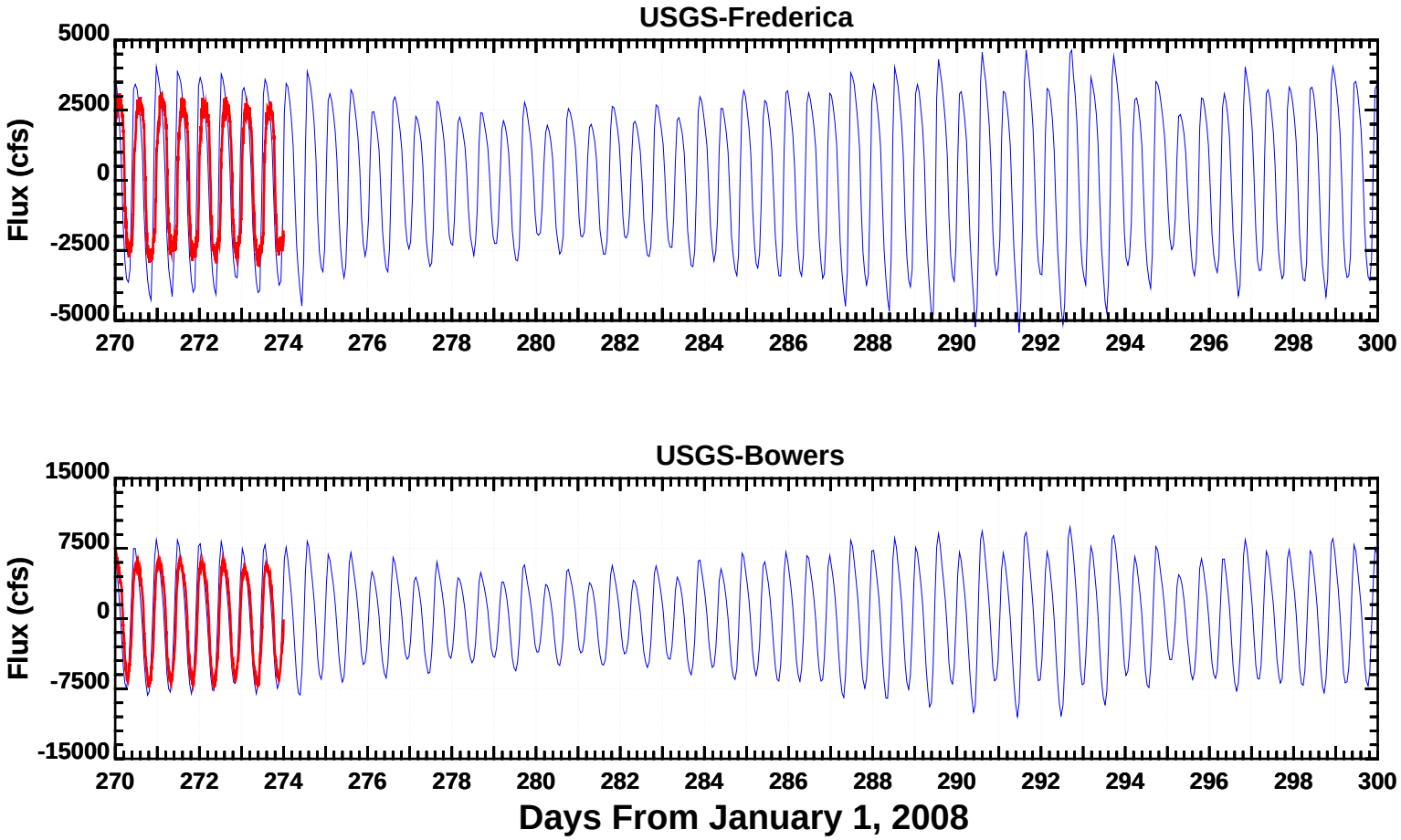

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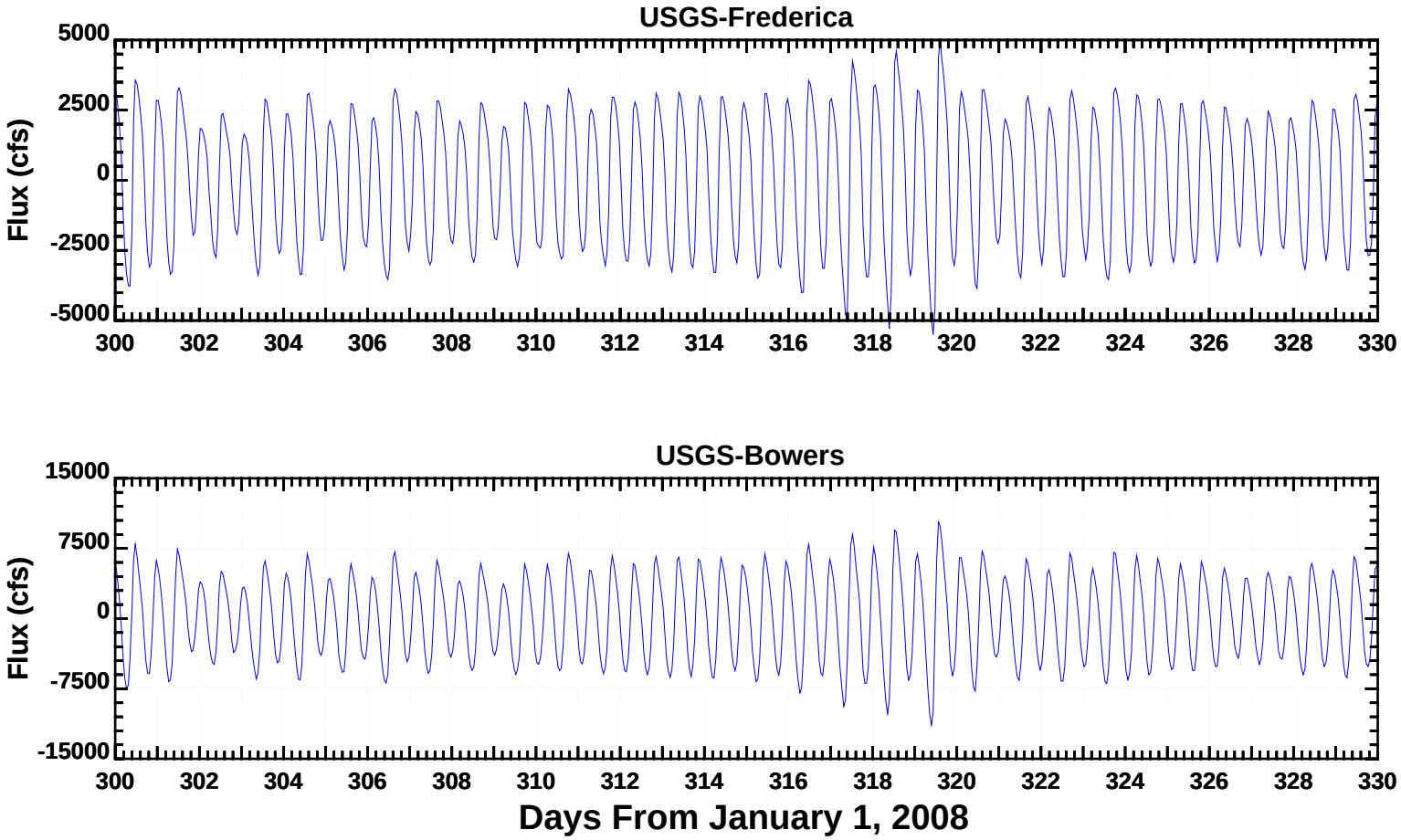

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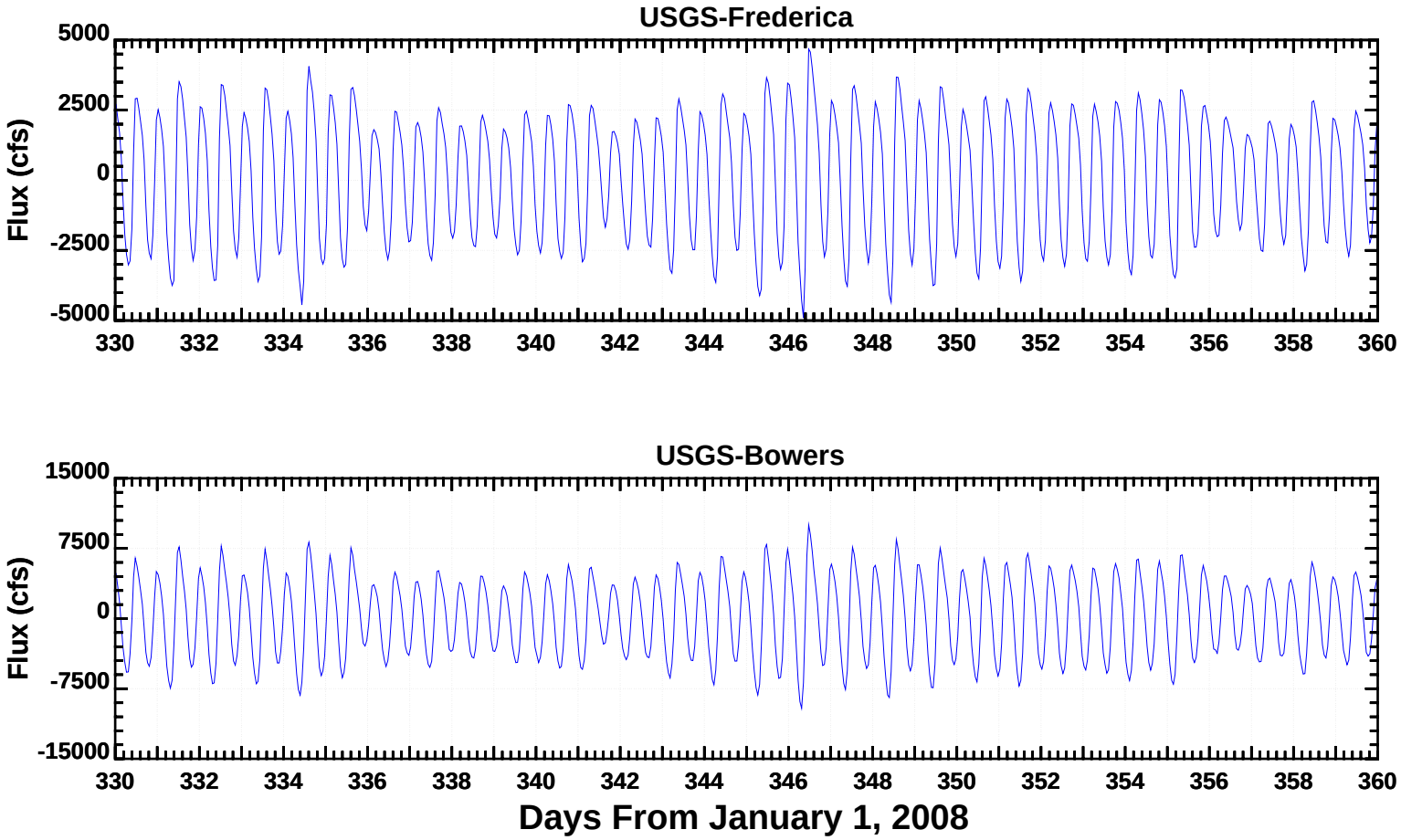

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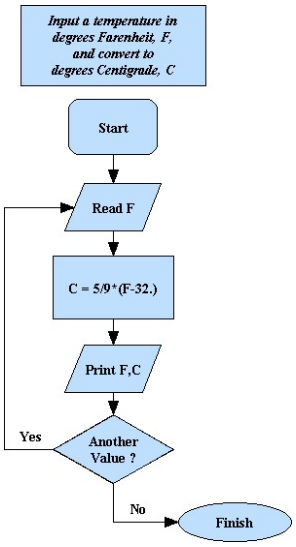
APPENDIX 7

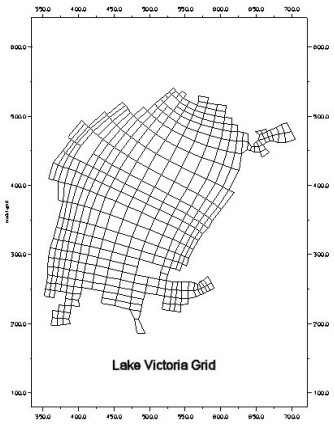
RCA DOCUMENTATION

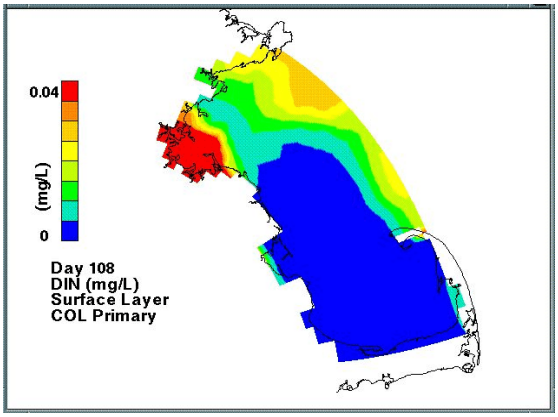
USER'S GUIDE FOR RCA
(Release 3.0)

JUNE 2004




```
C
C               SYSTEM 2 - PHYTOPLANKTON - WINTER DIATOMS
C
C         GET LIGHT ATTENUATION COEFFICIENTS

c$doacross local(ic,ir,il,chla,itot) , share(chlaveg,chlming,chlmaxg)
      DO 105 IC=1,NCOL
       DO 105 IR=1,NROW
        IF(FSM(IR,IC).LE.0)  GO TO 105
        DO 104 IL=1,NLAYR

C         COMPUTE TOTAL CHLOROPHYLL BASED ON
C         FIXED CARBON TO CHLOROPHYLL RATIO
          CHLA = PHYT1(IR,IC,IL)/CCHL1(IR,IC,IL)
               + PHYT2(IR,IC,IL)/CCHL2(IR,IC,IL)
          CHLAVEG(IR,IC,IL) = CHLAVEG(IR,IC,IL) + CHLA
          CHLMING(IR,IC,IL) = AMIN1(CHLMING(IR,IC,IL),CHLA)
          CHLMAXG(IR,IC,IL) = AMAX1(CHLMAXG(IR,IC,IL),CHLA)

C         INCLUDE SELF-SHADING EFFECT ON EXTINCTION COEFF

          SKE(IR,IC,IL) = KEBASE(IR,IC)+1000.*XKC*CHLA

C         LIGHT ATTENUATION

          IF(IL.EQ.1)   THEN
            ITOT=ISURF
          ELSE
            ITOT=ATTENL(IR,IC,IL-1)
          ENDIF

          ATTENL(IR,IC,IL) = ITOT*EXP(-SKE(IR,IC,IL)*HBAR(IR,IC)*DZ(IL))

  104   CONTINUE
  105 CONTINUE
```





HydroQual
Environmental
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PREFACE iii

1.0 Introduction 1
1.1 Characteristics of the Model 1
Generality 1
Mass Balance 1
Finite Difference 1
Solution Options 3
Variable Grid Size and Sigma-Level and Z-Level Coordinates 5
Flexible Specification of Pollutant Inputs 5
Flexible Disk Storage of Computational Results 5
Enhancements to RCA Version 3.0 6
1.2 Getting Started 7
Hydrodynamic Model Files 7
TUNER Subroutine 7
Generating a RCA Executable using "makerca3" 13
1.3 RCA File Structure 15

2.0 RCA Model Input Data Description 17
Group A: Model Descriptors (STDIN) 18
Group B: Print Control and Integration Control Information (STDIN) 22
Group C: Hydrodynamic Time Breaks and Scale Factors (STDIN) 32
Group D: Input File Names (STDIN) 36
Group E: Stability and Accuracy Criteria (STDIN) 41
Group F: End of Simulation Dumps (STDIN) 42
Group G: Boundary Concentrations (BCFILNA) 44
Group H: Point Source Loads (PSFILNA) 60
Group I: Nonpoint Source Loads (NPSFILNA) 66
Group J: Fall-line Loads (FLFILNA) 71
Group K: Atmospheric Loads (ATMFILNA) 76
Group L: Parameters, Constants and Time-variable Functions (PCFILNA) 85
Group M: Initial Conditions 93

APPENDIX A: INTEGRATED EUTROPHICATION/SEDIMENT NUTRIENT FLUX SUBMODELS
APPENDIX B: PATHOGEN MODEL
APPENDIX C: RESIDENCE TIME/DYE-TRACER MODEL
APPENDIX D: FILE DESCRIPTIONS FOR RCAF OUTPUT FILES VERSION 3.0 OF RCA

List of Tables

Table | Page

1. Example Listing of a Kinetic Subroutine - Tuner 8
2. RCA File Structure 15
3. Listing of Major Inputs to RCA by Group 17
4. Example of Standard Input File - STDIN 43
5. Example of Time-variable Sigma-level Boundary Conditions - BCFILNA 56
6. Example of Time-invariant Standard Level Boundary Condition Input - BCFILNA 59
7. Example of Time-invariant or Constant Point Source Input - PSFILNA . 65
8. Example of Time-invariant or Constant Point Source Input - PSFILNA . 82
9. Example of Time-variable Atmospheric Input - ATMFILNA 83
10. Example of a Parameter, Constants and Time-Variable Function Input File - PCFILNA 92

PREFACE

The purpose of this manual is to describe the inputs (and their associated formats) required to use the generalized HydroQual water quality model, RCA (an acronym for Row-Column AESOP). The manual also documents the procedure to follow to generate an executable version of the RCA program.

RCA is an extension to the family of generalized water quality models developed by HydroQual (and its predecessor firm Hydroscience). The original member of the family was known as WASP (Water Analysis Simulation Program) and was developed in the early 1970s at Hydroscience. This program was later provided to the U.S. EPA and continues to be supported by the EPA's Center for Water Quality Modeling. The most recent version is WASP6. The second generation of the family is known as AESOP (Advanced Ecological Systems Modeling Program) and was also developed by Hydroscience in the mid- to late-1970s. AESOP provided considerable improvements over the original WASP code including: a more computationally efficient numerical integration scheme (implicit integration); a more flexible computer coding approach for generating variable-configuration versions (i.e., number of systems by number of segments) of the code; addition of system dependent transport; and, in the mid-1980s, a preliminary link to HydroQual's generalized circulation model, ECOM, which was developed by Blumberg and Mellor (1987).

The newest member of the family, RCA (Row-Column AESOP), is meant to provide a WASP/AESOP-compatible computational framework for fine-mesh grids that can be used in conjunction with hydrodynamic applications for large lakes, rivers, and estuarine and coastal systems. RCA is able to directly interface with ECOM and ECOMSED and utilizes the same model grid and geometry and bathymetric information as used by the hydrodynamic model. RCA uses the transport fields that result from the hydrodynamic computation to compute the transport of water quality variables of interest within the study domain. In addition, since computing water quality on the same grid as used by the hydrodynamic model can be computationally expensive, options exist within RCA to take advantage of grid-aggregation programs. These grid-aggregation programs provide the user with a means of aggregating or collapsing the fine-grid hydrodynamic model into a coarser-grid representation suitable for water quality computational purposes.

Since RCA is a descendant of AESOP, much of the input structure and nomenclature is the same as is incorporated in AESOP. Therefore, a user familiar with AESOP should be able to set up a RCA input file without too much difficulty.

The interfacing between RCA and ECOM has been checked extensively (and recognition is extended to Kai-Yuan Yang and Eugenio Gomez-Reyes for their concerted efforts in this task) in this release of RCA. RCA has been demonstrated to exactly reproduce salinity fields computed by the ECOM/ECOMSED model, when run using the same integration procedure (the center-differenced in time and space, leap-frog scheme) as ECOM/ECOMSED. RCA also compares favorably to ECOM/ECOMSED salt computations when run using the upwind or backward difference scheme with Smolarkiewicz correction applied.

As stated above the purpose of this manual is to document the model inputs and input structure required to set up and perform a water quality simulation using RCA. As such the user's guide provides a brief description of the required input fields, the associated units (e.g. m/sec, kg/day, etc.) expected by RCA, and the input options available to the user should more than one type of input for a input group be permitted.

All ideas and critical comments concerning improvements (typos, sections requiring greater clarity in writing and purpose, etc.) which could be made to this document are welcomed by its author and should be directed to the undersigned. Kai-Yuan Yang is also recognized for his valuable contributions in integrating the various "versions" of RCA that have been spawned since RCA Version 2.0 into the new RCA 3.0 documented in this manual. Linda Jensen is also recognized for her patience and perseverance in preparing this Users Guide.

James J. Fitzpatrick

1.0 Introduction

RCA is a Row-Column version of AESOP, HydroQual's general purpose water quality modeling computer code. RCA was developed to directly interface with HydroQual's general circulation model, ECOMSED. As such, it will eliminate the need to use ECOSOP, the hydrodynamic to water quality model interface program that is required to link ECOMSED and AESOP.

Both RCA and AESOP solve general mass balance equations for water quality variables of interest. The principle difference between RCA and AESOP is that RCA obtains it advective and dispersive transport fields from a hydrodynamic model, whereas in AESOP the transport fields are specified by the user, based on kinematic box analysis or via calibration to a conservative tracer variable such as salinity.

A second difference between the two computer codes is that RCA has been written to take advantage of the parallel processing capabilities of CRAY or SGI computer systems and, therefore, should be faster than an equivalent AESOP model with the same number of segments.

1.1 Characteristics of the Model

Generality

RCA (as is AESOP) is a general purpose code developed to be used to evaluate a myriad of water quality problem settings. The user is able, via the development of a FORTRAN subroutine, to tailor RCA to address the specific water quality issues of the water body under investigation. The FORTRAN subroutine (called TUNER) prescribes the biological, chemical and/or physical kinetics or interrelationships between the relevant water quality variables of interest.

Mass Balance

RCA formulates mass balance equations for each model segment for each water quality constituent or state-variable of interest. These mass balance equations include all horizontal, lateral and vertical components of advective flow and dispersive mixing between model segments; physical, chemical and biological transformations between the water quality variables within a model segment; and point, nonpoint, fall-line and atmospheric inputs of the various water quality variables of interest.

Finite Difference

The partial differential equations, which form the water quality model, together with their boundary conditions, are solved using mass conserving finite difference techniques, Equation 1.

$$\frac{dM_i}{dt} = C_i \frac{dV_i}{dt} + V_i \frac{dC_i}{dt} \tag{1a}$$

$$\frac{dV_i}{dt} = \sum Q_{in} - \sum Q_{out} \tag{1b}$$

$$\frac{dC_i}{dt} = \sum \frac{Q_{in}}{V_i} \left(\alpha\, C_{up} + (1-\alpha)\, C_i\right) - \sum \frac{Q_{out}}{V_i} \left(\alpha\, C_i + (1-\alpha)\, C_{dwn}\right) + \sum \frac{R_{ij}}{V_i} \left(C_j - C_i\right) + \frac{W_i}{V_i} \pm k_i\, C_i \tag{1c}$$

where

M_i = mass of substance in segment i (kg),
C_i = concentration of substance in segment i (mg/L),
V_i = volume of segment i (m^3),
t = time,
Q_{in} = flow(s) entering segment i (m^3/sec),
Q_{out} = flow(s) leaving segment i (m^3/sec),
α = weighting or differencing factor,
= 1 for upwind scheme,
= 0.5 for central differencing scheme,
C_{up} = concentration of substance entering segment i due to Q_{in}, i.e., the concentration in the "upstream" segment (mg/L),
C_{dwn} = concentration of substance in the "downstream" segments associated with Q_{out} (mg/L),
R_{ij} = bulk exchange coefficient between segments i and j (m^3/sec),
C_j = concentration of substance in segment j (mg/L),
W_i = load or source input of substance i (kg/day),
k_i = reaction of substance in segment i (day^{-1}).

Each water quality segment or grid cell is assumed to be completely mixed, i.e., the concentrations of each water quality variable are uniform within the model segment or grid cell. Two finite difference approximations are available for the space derivatives: central difference, which introduces little or no artificial diffusion; and backward or upwind difference, which introduces an artificial diffusion that is proportional to the advective velocity and the grid size, as per Equation 2:

$$E_{num} = \frac{u\Delta x}{2} \tag{2}$$

where

E_{num} is the artificial or numerical diffusion (m^2/sec),
u is the advective velocity (m/sec),

Δx is the grid spacing (m).

Ideally, one would want to utilize central difference approximations in water quality modes, since no artificial diffusion is introduced into the model solution. However, the use of central differences can introduce other "problems" (but not errors) into the solution of the model equations. In particular, the use of central differences does not guarantee positivity, i.e. "negative" concentrations can be computed, although mass is conserved. Nor do central differences resolve step functions or delta functions, as might be introduced by point source inputs or intermittent CSO inputs, in a desirable fashion. The specification of these "abrupt" inputs can result in the generation of "saw-toothed" solutions, i.e. small oscillations about the mean concentration profile, along a spatial gradient, or "in a purely advective system" the apparent propagation of concentration upstream of a pollutant discharge. Again, these characteristics are not "errors" in the solution, but rather undesirable features resulting from the use of central differences in an attempt to eliminate numerical dispersion. While the central difference algorithm is available for use in RCA applications, it is recommended that it not be used because of the aforementioned problems.

As noted above, backward or upwind finite difference approximations to the continuous partial differential mass balance equation are also included as an option in RCA. While upwind differences do maintain positivity and do not generate "saw-toothed" solutions, they do introduce numerical dispersion into the finite difference equations. For certain problems, the magnitude of this numerical dispersion might be sufficient to eliminate or significantly reduce concentration gradients in the vertical or horizontal planes. To partially alleviate this problem, RCA has been coded with an additional user selectable option that permits the use of an upwind corrector scheme, based on Smolarkiewicz's antidiffusive velocity algorithm, which reduces the magnitude of the numerical dispersion in the finite difference solution. While this option can significantly improve the resolution of vertical and horizontal concentration gradients by RCA, it does so at the cost of additional computational overhead (20 to 50 percent increases in run-time).

Solution Options

RCA provides the user with a number of numerical schemes for solving the water quality mass balance equations. In time-variable mode, the user may utilize one of five explicit time-stepping algorithms, all of which require that the time-step (Δt) obey Equation 3:

$$\Delta t \le \text{Min}\left(\frac{V}{\sum Q + \sum R + kV}\right) \tag{3}$$

where

Δt is the maximum time-step or integration interval (secs),
V is the segment volume (m^3),
$\sum Q$ is the sum of the advective fluxes leaving the segment (m^3/sec),

$\sum_{kV}R$ is the sum of the dispersive fluxes leaving the segment (m^3/sec),
is the loss rate of material due to kinetic reactions (m^3/sec).

The five algorithms include: (1) a centered-in-time Smolarkiewicz-corrected upwind scheme; (2) forward-in-time (first order Euler) with and (3) without Smolarkiewicz correction upwind schemes; (4) and split-timestep with and (5) without Smolarkiewicz correction upwind schemes.

Two modifications have been implemented within RCA to reduce run times for computationally-intensive applications. First, an option to evaluate the kinetic portion of the mass balance equation on a less frequent basis than the transport portion of the equation is evaluated and, second, a split-timestep integration procedure. The first modification assumes that the kinetics or reaction rates of the problem have much lower time constants than do the transport, i.e., the biological or chemical reaction rates on the order of 0.01 to 0.2/day versus equivalent transport rates of 1 to 10/day or greater (equivalent to detention times of 1 to 0.1 days or less). If, for example, a model investigation of eutrophication requires a timestep of 0.01 day (about a quarter hour) to meet the stability criteria of Equation 3, a user might wish to select the option in RCA which permits the kinetic subroutine (TUNER) to be evaluated every 0.10 days, rather the 0.01 day required for the transport. Selecting this option might permit a savings of 20 to 30 percent of the runtime. However, it is recommended that all final calibration runs and all projection runs be performed with the kinetic routine called every transport timestep. This ensures that no "errors" are introduced into the model solution. One way to determine the maximum stepsize for evaluating the kinetic subroutine is to perform a number of simulations, wherein the stepsize for evaluating the kinetics is increased each time and the computational results are compared against a run wherein the kinetic and transport stepsizes are the same, i.e., the base case. The user could then pick a stepsize value for evaluating the kinetics, which minimizes computer runtime, but does not significantly affect the computational results relative to the base case.

The second modification (available in the "in-house" version of RCA), split time-step integration, permits the integration of the "critical detention time" segments using a small timestep to maintain stability for the critical segments, while integrating the remaining (majority) of the water quality segments using a larger (factor of 5 to 10) timestep than is required for the critical segments. One of the options available in RCA is to have RCA step through the entire simulation period (or hydrodynamic transport file) to determine the critical integration timesteps for each averaging period within the hydrodynamic record. This diagnostic analysis provides the absolute "critical" timestep required to maintain stability (as defined by Equation 3) and, in addition the critical timestep for 1, 5, 10, 15 and 20 percent of the computational water quality grid. For example, a water quality grid with 5,000 segments might have the following "average" critical timestep characteristics: an absolute critical timestep of 0.0057 days; 1 percent (50 segments) with a critical timestep of 0.0091 days or less; 5 percent (250 segments) with a critical timestep of 0.012 days or less; 10 percent (500 segments) with a critical timestep of 0.021 days or

less; 15 percent (750 segments) with a critical timestep of 0.026 days or less; and 20 percent (1000 segments) with a critical timestep of 0.031 days or less. The user could, then, using the appropriate RCA input options, select a critical or split timestep of 0.005 days and a full timestep of 0.025 days (and possibly further select a kinetic subroutine timestep of 0.10 days). This could result in an overall 50 to 75 percent reduction in total computational time over the base case, where all segments are integrated using a timestep of 0.005 days and a kinetic timestep of 0.005 days. Once again the user is urged to perform a number of runs in order to evaluate the sensitivity of the model solution to the split time-step integration stepsize.

Variable Grid Size and Sigma-Level and Z-Level Coordinates

Since RCA depends upon the hydrodynamic model, ECOMSED, for its model geometry and transport fields, it employs the same variable horizontal grid and vertical (either sigma- or Z-level) coordinate system as does ECOMSED. (For further information on sigma coordinates and the HydroQual general circulation model the user is referred to the ECOMSED Primer.) While the user may run RCA using a sigma-level coordinate system, RCA will still permit the user to specify boundary condition and initial conditon inputs using standard (or fixed depth) levels. RCA then transforms the standard level inputs to the sigma-level grid using linear interpolation.

Flexible Specification of Pollutant Inputs

RCA permits the user to specify pollutant inputs using any or all of four categories: point source (WWTPs/CSOs/SSOs), nonpoint source (urban/agricultural/ watershed runoff), fall-line or riverine sources, and atmospheric source (wetfall/dryfall). Although all pollutant inputs could be organized and input into the model as one loading group, as is done in AESOP, it was thought that permitting these four groupings in RCA would provide the user with greater flexibility in structuring his/her input deck. By splitting the inputs into four groups, the user can perform sensitivity or component analysis much easier by just setting the scale factor for the appropriate group to the desired value rather than be forced to edit the input file and modify a large group of numbers that correspond to the loading group to be analyzed. An example of this would be to reduce all STP and CSO inputs by fifty percent but keep all non-point source, riverine and atmospheric loadings the same. To do this the user would need only to set the scale factor of the point source loading group to 0.5, leaving all other inputs to the model the same.

Flexible Disk Storage of Computational Results

RCA permits the user two types of storage for computational results: (1) domain-wide or "global" dumps of all state-variables at "coarse" time intervals; and/or (2) detailed dumps for selected segments at "fine" time intervals. In the first instance a user could save concentrations for all state-variables over the entire model domain for a period of a year using 10 day intervals. This would permit the user using the HydroQual post-processing tool H4D to generate contour plots or time-variable movies for any plane within the model. When using detailed dumps a user

can generate more detailed information concerning model performance by saving secondary variables, such as total extinction coefficients, nutrient limitation terms, etc., as well as the state-variable concentrations for selected segments within the model, at one day intervals. The user could then generate detailed time-series plots using HydroQual post-processing tool GDP. (Note: the information contained in the detailed dumps is determined in the TUNER subroutine via a series of CALLs to the subroute RCAWBUF. A more complete description of the structure of the RCA output files is contained in Appendix D.)

Enhancements to RCA Version 3.0

A number of enhancements have been made between this release of RCA (Version 3.0) and previous versions of the code. These include:

- implementation of an integer "clock" to control the overall numerical simulation and the updating of hydrodynamic, load, and boundary condition inputs,
- a revised input structure for specifying point, nonpoint, and fall line loads that includes provision for specifying a load identification table,
- implementation of piece-wise linear interpolation of load inputs,
- greater checking for input errors, and
- use of comment or header records for input records to facilitate editing or modification of required input information.

In previous versions of RCA a real-time clock (in days) was used by RCA to keep track of the simulation time and coordinate with updating of time-variable models inputs such as generated by the hydrodynamic model ECOMSED or loadings and/or boundary conditions. Unfortunately, the use of REAL variables can result in numerical round-off errors after repeated addition of fractions. This can result in synchronization errors when updating the hydrodynamic model inputs. Therefore, RCA has been modified to use INTEGER variables to specify the numerical time-step for integration and to keep track of the simulation time. These internal variables will operate in units of seconds.

RCA has also been modified so that pollutant loads can be specified using piece-wise linear interpolation rather than just step function changes. As an example suppose a user specifies the following time-series input for a pollutant load:

value	time	value	time	value	time
10.0	0.0	20.0	50.0	40.0	100.

If the user selected the step-function option, the value of the pollutant load at time = 25 would be 10.0. If, however, the user selected piece-wise linear interpolation the value at time = 25 would be 15.

Version 3.0 of RCA has also been improved to provide greater checking of model inputs. For example, RCA will check to make sure that the model segment to which a pollutant load is assigned is a valid water cell.

Finally, for normal Ascii (or card-image) files, RCA has been modified to include a "comment" or "header" record to be read before every major input record. Although the user may leave these records "blank" without any consequence, use of these comment records to list or describe the input data to follow may facilitate subsequent editing or modification of the input data required to run the model. It should be noted, however, that comment or header records SHOULD NOT be included in binary files.

1.2 Getting Started

Hydrodynamic Model Files

In order to begin, the user will, of course, need a hydrodynamic model. The hydrodynamic model code, ECOMSED, generates three output files (four, if the user chooses to save only the water cells of the model grid) which are required by RCA. These files are named, "gcm_geom," which contains information concerning model geometry, "gcm_tran" which contains the advective and dispersive transport fields, and "gcm_gdiff" which contains information relating to the locations and time-variable discharge volumes associated with any diffusers or outfalls included in the hydrodynamic model (and "wet_grid," which contains the locations of the water cells in the model domain, if the "water cells only" option is chosen). The user will need to move, copy, or link the "gcm_geom" and "wet_grid", if appropriate, files to the directory in which the water quality model and the executable version of RCA are to reside. The "gcm_tran" file(s) and "gcm_gdiff" file(s), however, need not be moved, copied, or linked. They can remain in a separate directory, file folder, or disk drive.

TUNER Subroutine

Next the user will be required to supply a FORTRAN subroutine, which contains the state-equations or kinetics for the water quality problem of interest. The subroutine should be called "TUNER" (as in SUBROUTINE TUNER) but may be maintained on the system using any name that the user desires (for example, lisem2.f). An example TUNER, written for a one-system conservative tracer, which can also be used to calculate residence time of a waterbody (and which can be easily expanded to three-systems) is presented in Table 1. Appendices A and B provide descriptions of more complex TUNERS; one that is HydroQual's current implementation of eutrophication kinetics and one that is HydroQual's current implementation of coliform kinetics and that are provided as part of the public domain release of RCA. Appendix C provides more detail on the residence time subroutine presented in Table 1.

TABLE 1. EXAMPLE LISTING OF A KINETIC SUBROUTINE - TUNER

```
C
C**********************************************************************
C
      SUBROUTINE   TUNER
C
C**********************************************************************
C
C          RESIDENCE TIME MODEL - COMPUTE RESIDENCE TIME OF A SEGMENT(s)
C          ------------------------------------------------------------
C               (Note: current version is set up for 1 system, but may
C                  be readily expanded to 2 or 3 systems by uncommenting
C                  the appropriate FORTRAN statements in the code)
C
C**********************************************************************
C
C     SYSTEMS                                                    UNITS
C     -------                                                    -----
C        1 - DYE1  - CONCENTRATION OF DYE                         MG/L
C        2 - DYE2  - CONCENTRATION OF DYE                         MG/L
C        3 - DYE3  - CONCENTRATION OF DYE                         MG/L
C
C**********************************************************************
C
C     CONSTANTS
C     ---------
C
C   NO   NAME      DESCRIPTION                                   UNITS
C   --   --------  --------------------------------------------  -----
C    1   DYEDIS1   DYE DISTRIBUTION OPTION
C                  = 0, ASSIGN INITIAL DYE CONCENTRATIONS UNIFORMLY
C                       THROUGHOUT THE WATER COLUMN (I.E., TOP TO
C                       BOTTOM) USING PARAM2D(1)
C                       PARAM2D(2) WILL BE USED TO SPECIFY THE DOMAIN
C                       OVER WHICH THE RESIDENCE TIME WILL BE COMPUTED
C                  = 1, INITIAL DYE CONCENTRATIONS WILL BE SPECIFIED
C                       ON A SEGMENT BY SEGMENT BASIS USING PARAM3D(1)
C                       PARAM3D(2) WILL BE USED TO SPECIFY THE DOMAIN
C                       OVER WHICH THE RESIDENCE TIME WILL BE COMPUTED
C    2   TIMEDYE1  TIME TO RELEASE DYE 1
C    3   DECAY1    DECAY RATE FOR DYE 1                           /DAY
C    4   DYEDIS2   DYE DISTRIBUTION OPTION
C                  = 0, ASSIGN INITIAL DYE CONCENTRATIONS UNIFORMLY
C                       THROUGHOUT THE WATER COLUMN (I.E., TOP TO
C                       BOTTOM) USING PARAM2D(3)
C                       PARAM2D(4) WILL BE USED TO SPECIFY THE DOMAIN
C                       OVER WHICH THE RESIDENCE TIME WILL BE COMPUTED
C                  = 1, INITIAL DYE CONCENTRATIONS WILL BE SPECIFIED
C                       ON A SEGMENT BY SEGMENT BASIS USING PARAM3D(3)
C                       PARAM3D(4) WILL BE USED TO SPECIFY THE DOMAIN
C                       OVER WHICH THE RESIDENCE TIME WILL BE COMPUTED
C    5   TIMEDYE2  TIME TO RELEASE DYE 2
C    6   DECAY2    DECAY RATE FOR DYE 2                           /DAY
C    7   DYEDIS3   DYE DISTRIBUTION OPTION
C                  = 0, ASSIGN INITIAL DYE CONCENTRATIONS UNIFORMLY
C                       THROUGHOUT THE WATER COLUMN (I.E., TOP TO
C                       BOTTOM) USING PARAM2D(5)
C                       PARAM2D(6) WILL BE USED TO SPECIFY THE DOMAIN
C                       OVER WHICH THE RESIDENCE TIME WILL BE COMPUTED
C                  = 1, INITIAL DYE CONCENTRATIONS WILL BE SPECIFIED
C                       ON A SEGMENT BY SEGMENT BASIS USING PARAM3D(5)
C                       PARAM3D(6) WILL BE USED TO SPECIFY THE DOMAIN
C                       OVER WHICH THE RESIDENCE TIME WILL BE COMPUTED
C    8   TIMEDYE3  TIME TO RELEASE DYE 3
C    9   DECAY3    DECAY RATE FOR DYE 3                           /DAY
C
C**********************************************************************
C
C     2-D PARAMETERS
C     --------------
C
C       NO  NAME          DESCRIPTION                            UNITS
C      ---  --------  ----------------------------------------   -----
C        1  DYE1IC2   INITIAL CONDITIONS FOR DYE1                 MG/L
C        2  DOMAIN1   DOMAIN FOR DETERMINING RESIDENCE TIME 1
C        3  DYE2IC2   INITIAL CONDITIONS FOR DYE2                 MG/L
C        4  DOMAIN2   DOMAIN FOR DETERMINING RESIDENCE TIME 2
C        5  DYE3IC2   INITIAL CONDITIONS FOR DYE3                 MG/L
C        6  DOMAIN3   DOMAIN FOR DETERMINING RESIDENCE TIME 3
C
C**********************************************************************
C
```

TABLE 1. EXAMPLE LISTING OF A KINETIC SUBROUTINE - TUNER (Cont.)

```
C     3-D PARAMETERS
C     --------------
C
C       NO  NAME           DESCRIPTION                                UNITS
C      ---  --------  ----------------------------------------   -----
C        1  DYE1IC3   INITIAL CONDITIONS FOR DYE1                  MG/L
C        2  DOMAIN1   DOMAIN FOR DETERMINING RESIDENCE TIME 1
C        3  DYE2IC3   INITIAL CONDITIONS FOR DYE2                  MG/L
C        4  DOMAIN2   DOMAIN FOR DETERMINING RESIDENCE TIME 2
C        5  DYE3IC3   INITIAL CONDITIONS FOR DYE3                  MG/L
C        6  DOMAIN3   DOMAIN FOR DETERMINING RESIDENCE TIME 3
C
C***********************************************************************
C
C     TIME-VARIABLE FUNCTIONS
C     -----------------------
C          NONE
C
C***********************************************************************
C
      SAVE

      INCLUDE 'RCACM'
      CHARACTER   GDNAMES(NOSYS)*8,DDNAMES(5,NOSYS)*8

C        STATE-VARIABLES
      REAL
     .       DYE1(NX,NY,NZ)
CC   .     , DYE2(NX,NY,NZ)
CC   .     , DYE3(NX,NY,NZ)
      EQUIVALENCE
     .       (CARAY(1,1,1,1),DYE1(1,1,1))
CC   .     , (CARAY(1,1,1,2),DYE2(1,1,1))
CC   .     , (CARAY(1,1,1,3),DYE3(1,1,1))
      REAL
     .       DYE_DDA(NX,NY,NZ,NOSYS)
     .     , DYE_DMIN(NX,NY,NZ,NOSYS)
     .     , DYE_DMAX(NX,NY,NZ,NOSYS)
     .     , DYE_GDA(NX,NY,NZ,NOSYS)
     .     , DYE1_GDA(NX,NY,NZ)
C    .     , DYE2_GDA(NX,NY,NZ)
C    .     , DYE3_GDA(NX,NY,NZ)
      EQUIVALENCE
     .       (DYE_GDA(1,1,1,1),DYE1_GDA(1,1,1))
C    .     , (DYE_GDA(1,1,1,2),DYE2_GDA(1,1,1))
C    .     , (DYE_GDA(1,1,1,3),DYE3_GDA(1,1,1))

C        CONSTANTS
      EQUIVALENCE
     .    (CONST(1),DYEDIS1)   , (CONST(2),TIMEDYE1) , (CONST(3),DECAY1) ,
     .    (CONST(4),DYEDIS2)   , (CONST(5),TIMEDYE2) , (CONST(6),DECAY2) ,
     .    (CONST(7),DYEDIS3)   , (CONST(8),TIMEDYE3) , (CONST(9),DECAY3)

      REAL*8    TOTMASIC(NOSYS),TOTMASREG(NOSYS),TOTMASALL(NOSYS)

      INTEGER*2  SYSGDP(40)
C        INITIAL -SYSBY- SETTINGS
      DATA  SYSGDP/40*1/

C        PROVIDE INITIALIZATION, IF FIRST TIME THROUGH -FABLE-
      IF(INITB.EQ.1)   GO TO 50
C        SET-UP AND WRITE INFORMATION NEEDED BY GDP
        GDNAMES( 1) = 'DYE1'
C       GDNAMES( 2) = 'DYE2'
C       GDNAMES( 3) = 'DYE3'
      DO ISYS=1,NOSYS
         SYSGDP(ISYS) = SYSBY(ISYS)
      ENDDO
      REWIND(10)
      WRITE(10)    NX,NY,NZ,NOSYS,NOSYS
      WRITE(10)    GDNAMES
      WRITE(10)    SYSGDP
      WRITE(10)    FSM
C        WRITE DDNAMES TO RCAF12
C         (NOTE: IF SYSTEM 2 AND/OR 3 ACTIVATED ADD APPROPRIATE DDNAMES)
      IF(IDDOPT.EQ.0) THEN
       DDNAMES(1,1)='    DYE1'
       DDNAMES(1,2)='   DUMMY'
       DDNAMES(1,3)='IC MASS1'
       DDNAMES(1,4)='REGNMAS1'
       DDNAMES(1,5)='DOMNMAS1'
      ELSE
```

TABLE 1. EXAMPLE LISTING OF A KINETIC SUBROUTINE - TUNER (Cont.)

```
       DDNAMES(1,1)='AVE DYE1'
       DDNAMES(1,2)='MAX DYE1'
       DDNAMES(1,3)='IC MASS1'
       DDNAMES(1,4)='REGNMAS1'
       DDNAMES(1,5)='DOMNMAS1'
      ENDIF
      WRITE(12)  DDNAMES

C        SET INITIAL CONDITIONS
      DO 30 ISYS=1,NOSYS
       IF(CONST(3*(ISYS-1)+1).EQ.0 .AND. CONST(3*(ISYS-1)+2).EQ.0.) THEN
         DO 10 IZ=1,NZ
          DO 10 IY=1,NY
           DO 10 IX=1,NX
            IF(FSM(IX,IY).EQ.1.)
     .           CARAY(IX,IY,IZ,ISYS) = PARAM2D(IX,IY,2*(ISYS-1)+1)
   10    CONTINUE
C        RESET CONSTANT SO DYE IS NOT PUT INTO SYSTEM AGAIN
         CONST(3*(ISYS-1)+2)=9.99E+9
       ELSEIF(CONST(3*(ISYS-1)+1).EQ.1 .AND. CONST(3*(ISYS-1)+2).EQ.0.)
     .  THEN
         DO 20 IZ=1,NZ
          DO 20 IY=1,NY
           DO 20 IX=1,NX
            IF(FSM(IX,IY).EQ.1.)
     .           CARAY(IX,IY,IZ,ISYS) = PARAM3D(IX,IY,IZ,2*(ISYS-1)+1)
   20    CONTINUE
         CONST(3*(ISYS-1)+2)=9.99E+9
       ENDIF
   30 CONTINUE
      CALL RCA09
      IREC=IREC-1

C        INITIALIZE ARRAY FOR GLOBAL DUMP AVERAGING, IF REQUIRED
      IF(IGDOPT.EQ.1)  THEN
       DO 40 ISYS=1,NOSYS
        DO 35 IZ=1,NZ
         DO 35 IY=1,NY
          DO 35 IX=1,NX
           DYE_GDA(IX,IY,IZ,ISYS) = 0.
           DYE_DDA(IX,IY,IZ,ISYS) = 0.
           DYE_DMIN(IX,IY,IZ,ISYS) = 1000.
           DYE_DMAX(IX,IY,IZ,ISYS) = -1000.
   35   CONTINUE
   40  CONTINUE
       IAVGGDCNTR = 0
       IAVGDDCNTR = 0
       IAVGPPCNTR = 0
      ENDIF
      DUMMY=0.0

   50 CONTINUE

C        CHECK IF TIME TO LOAD ANOTHER DYE
      DO 100 ISYS=1,NOSYS
       IF(CONST(3*(ISYS-1)+1).EQ.0 .AND. TIME.GT.CONST(3*(ISYS-1)+2))
     .  THEN
         WRITE(OUT,1200)  ISYS,TIME
 1200    FORMAT(//10X,'LOADING TRACER #',I2,' AT TIME',F8.2)
         DO 70 IZ=1,NZ
          DO 70 IY=1,NY
           DO 70 IX=1,NX
            CARAY(IX,IY,IZ,ISYS) = PARAM2D(IX,IY,2*(ISYS-1)+1)
   70    CONTINUE
         CONST(3*(ISYS-1)+2)=9.99E+9
         CALL RCA09
         IREC=IREC-1
       ELSEIF(CONST(3*(ISYS-1)+1).EQ.1.AND.TIME.GT.CONST(3*(ISYS-1)+2))
     .  THEN
         WRITE(OUT,1200)  ISYS,TIME
         DO 80 IZ=1,NZ
          DO 80 IY=1,NY
           DO 80 IX=1,NX
            CARAY(IX,IY,IZ,ISYS) = PARAM3D(IX,IY,IZ,2*(ISYS-1)+1)
   80    CONTINUE
         CONST(3*(ISYS-1)+2)=9.99E+9
         CALL RCA09
         IREC=IREC-1
       ENDIF
  100 CONTINUE

C        LOOP FOR DETAILED DUMP AVERAGING, IF REQUIRED
```

TABLE 1. EXAMPLE LISTING OF A KINETIC SUBROUTINE - TUNER (Cont.)

```
      IF(IDDOPT.EQ.1)  THEN
       DO 125 ISYS=1,NOSYS
        DO 120 IZ=1,NZ
         DO 120 IY=1,NY
          DO 120 IX=1,NX
            DYE_DDA(IX,IY,IZ,ISYS) = DYE_DDA(IX,IY,IZ,ISYS)
     .           + CARAY(IX,IY,IZ,ISYS)
            DYE_DMIN(IX,IY,IZ,ISYS) =
     .           AMIN1(DYE_DMIN(IX,IY,IZ,ISYS),CARAY(IX,IY,IZ,ISYS))
            DYE_DMAX(IX,IY,IZ,ISYS) =
     .           AMAX1(DYE_DMAX(IX,IY,IZ,ISYS),CARAY(IX,IY,IZ,ISYS))
  120   CONTINUE
  125  CONTINUE
       IAVGDDCNTR = IAVGDDCNTR + 1
      ENDIF

C        SYSTEM 1(-3) - DYE1(-3)
      DO 150 ISYS=1,NOSYS
       TOTMASIC(ISYS)=0.
       TOTMASREG(ISYS)=0.
       TOTMASALL(ISYS)=0.
       DO 135 IZ=1,NZ
        DO 135 IY=1,NY
         DO 135 IX=1,NX
          IF(FSM(IX,IY).NE.1.)  GO TO 135
          CDARAY(IX,IY,IZ,ISYS) = -CONST(3*ISYS)*CARAY(IX,IY,IZ,ISYS)
          IF(IDISK.NE.0) THEN
           IF(CONST(3*(ISYS-1)+1).EQ.0.) THEN
            IF(PARAM2D(IX,IY,2*(ISYS-1)+1).GT.0.)  TOTMASIC(ISYS) =
     .           TOTMASIC(ISYS) + BVOL(IX,IY,IZ)*CARAY(IX,IY,IZ,ISYS)
           IF(PARAM2D(IX,IY,2*ISYS).GT.0.)  TOTMASREG(ISYS) =
     .           TOTMASREG(ISYS) + BVOL(IX,IY,IZ)*CARAY(IX,IY,IZ,ISYS)
          ELSE
           IF(PARAM3D(IX,IY,IZ,2*(ISYS-1)+1).GT.0.)  TOTMASIC(ISYS) =
     .           TOTMASIC(ISYS) + BVOL(IX,IY,IZ)*CARAY(IX,IY,IZ,ISYS)
           IF(PARAM3D(IX,IY,IZ,2*ISYS).GT.0.)  TOTMASREG(ISYS) =
     .           TOTMASREG(ISYS) + BVOL(IX,IY,IZ)*CARAY(IX,IY,IZ,ISYS)
          ENDIF
          TOTMASALL(ISYS) =
     .           TOTMASALL(ISYS) + BVOL(IX,IY,IZ)*CARAY(IX,IY,IZ,ISYS)
         ENDIF
  135  CONTINUE
       IF(IDISK.EQ.2 .OR. IDISK.EQ.3)  THEN
        DO 145 IDMP=1,NDMPS
         IX = IFDMPS(IDMP,1)
         IY = IFDMPS(IDMP,2)
         IZ = IFDMPS(IDMP,3)
         IF(IDDOPT.EQ.0)  THEN
           CALL RCAWBUF(ISYS,CARAY(IX,IY,IZ,ISYS),dummy
     .          ,SNGL(TOTMASIC(ISYS)),SNGL(TOTMASREG(ISYS))
     .          ,SNGL(TOTMASALL(ISYS)))
         ELSE
           CALL RCAWBUF(ISYS,CARAY(IX,IY,IZ,ISYS)/IAVGDDCNTR
     .          ,DYE_DMAX(IX,IY,IZ,ISYS)
     .          ,SNGL(TOTMASIC(ISYS)),SNGL(TOTMASREG(ISYS))
     .          ,SNGL(TOTMASALL(ISYS)))
         ENDIF
  145   CONTINUE
       ENDIF
  150 CONTINUE

C        CONVERT TO MASS UNITS
c$doacross local(iz,iy,ix,isys)
       DO 200 ISYS=1,NOSYS
        DO 200 IZ=1,NZ
         DO 200 IY=1,NY
          DO 200 IX=1,NX
          CDARAY(IX,IY,IZ,ISYS) = BVOL(IX,IY,IZ)*CDARAY(IX,IY,IZ,ISYS)
  200  CONTINUE

      IF(IDISK.EQ.2 .OR. IDISK.EQ.3)  THEN
C        CLOSE BUFFER AND WRITE TO DISK
       CALL RCAWRIT

       DO ISYS=1,NOSYS
        WRITE(OUT,2500)   TOTMASIC(ISYS)/1000.,TOTMASREG(ISYS)/1000.
     .                   ,TOTMASALL(ISYS)/1000.
 2500   FORMAT(
     .     /10X,'INITIAL CONDITION REGIONAL TOTAL MASS =',E13.5,' KG'
     .     /10X,'REGIONAL TOTAL MASS =',E13.5,' KG'/
     .     /10X,'DOMAIN TOTAL MASS =',E13.5,' KG'/)
       ENDDO
```

TABLE 1. EXAMPLE LISTING OF A KINETIC SUBROUTINE - TUNER (Cont.)

```
C         RE-INITIALIZE ARRAY FOR DETAILED DUMP AVERAGING, IF REQUIRED
        IF(IDDOPT.EQ.1)  THEN
         DO 215 ISYS=1,NOSYS
          DO 210 IZ=1,NZ
           DO 210 IY=1,NY
            DO 210 IX=1,NX
              DYE_DDA(IX,IY,IZ,ISYS) = 0.
              DYE_DMIN(IX,IY,IZ,ISYS) = 1000.
              DYE_DMAX(IX,IY,IZ,ISYS) = -1000.
  210    CONTINUE
  215   CONTINUE
         IAVGDDCNTR = 0
        ENDIF
       ENDIF
C         PERFORM GLOBAL DUMP AVERAGING, IF REQUIRED
       IF(IGDOPT.EQ.1)  THEN
        DO 225 ISYS=1,NOSYS
         DO 220 IZ=1,NZ
          DO 220 IY=1,NY
           DO 220 IX=1,NX
             DYE_GDA(IX,IY,IZ,ISYS) = DYE_GDA(IX,IY,IZ,ISYS)
     .                              + CARAY(IX,IY,IZ,ISYS)
  220   CONTINUE
  225  CONTINUE
       ENDIF
       IAVGGDCNTR = IAVGGDCNTR + 1

C          CHECK IF TIME TO DUMP TO DISK
       IF(IDISK.EQ.0)   RETURN
C         GLOBAL DUMPS
       IF(IDISK.EQ.1 .OR. IDISK.EQ.3)  THEN
        IF(IGDOPT.EQ.0)  THEN
          WRITE(10)   TIME
          WRITE(11)   DYE1
C         WRITE(11)  DYE2
C         WRITE(11)  DYE3
        ELSE
          DO 365 ISYS=1,NOSYS
           DO 360 IZ=1,NZ
            DO 360 IY=1,NY
             DO 360 IX=1,NX
              DYE_GDA(IX,IY,IZ,ISYS) = DYE_GDA(IX,IY,IZ,ISYS)/
     .                                                 FLOAT(IAVGGDCNTR)
  360     CONTINUE
  365    CONTINUE
          WRITE(10)   TIME - FLOAT(IPRNTGSECS)/86400./2.
          WRITE(11)   DYE1_GDA
C         WRITE(11)   DYE2_GDA
C         WRITE(11)   DYE3_GDA
        ENDIF
        IF(IGDOPT.EQ.1)  THEN
         DO 385 ISYS=1,NOSYS
          DO 380 IZ=1,NZ
           DO 380 IY=1,NY
            DO 380 IX=1,NX
             DYE_GDA(IX,IY,IZ,ISYS) = 0.
  380    CONTINUE
  385   CONTINUE
        ENDIF
        IAVGGDCNTR = 0
        IAVGPPCNTR = 0
       ENDIF

C         INITIAL CONDITION FILE
       REWIND 15
       WRITE(15)  CARAY

       RETURN

  900 WRITE(OUT,9990)
 9990 FORMAT(///5X,'INPUT ERROR WHILE READING IGDOPT,IDDOPT'//)
       CALL EXIT
       END
```

Generating a RCA Executable using "makerca3"

In order to use RCA, the user should copy the RCA source code and makerca3 script from App_Server\Install\RCA to his/her working directory. The user would then execute the "makerca3" script from his/her working directory. This script has options for copying the RCA source code to the working directory, editing various files, compiling the RCA code and building an executable version of RCA. After copying the files, the first task is to edit the "RCACM" file to set the appropriate parameters. These are at the top of the RCACM file in the first PARAMETER statement. The following is a list of variables to be set with a brief description of each:

Variable	Definition
nx	number of grid cells in the x-axis of the model
ny	number of grid cells in the y-axis of in the model
nz	number of grid cells or layers in the vertical plane of the model
nosys	number of systems or water quality state-variables

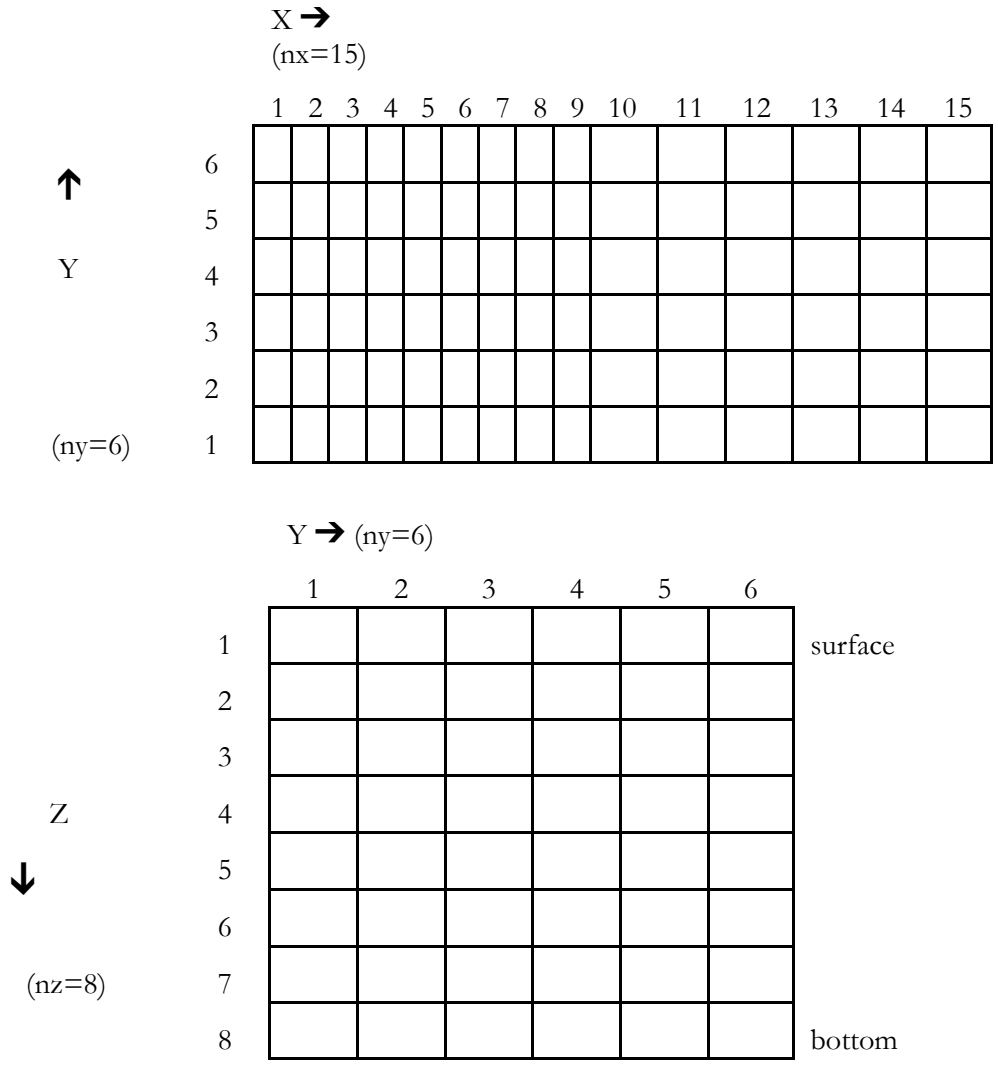
The first few lines of RCACM are listed below:

```
C
C    CONFIGURATION, REAL, INTEGER, AND COMMON CARDS FOR RCA
C                                   Version 3.0

      PARAMETER  (NX=nx,NY=ny,NZ=nz,NOSYS=nosys)
      PARAMETER  (NPARM2D=10,NPARM3D=6,NBC=750,NWK=750)
      PARAMETER  (MXCONS=250,MXFUNC=20,MXFUNCT=400)
      PARAMETER (MXHYDFILES=36,NHYD=15000,NSL=100,NSLC=100)
      PARAMETER  (MXSEGSPLT=(NX*NY*NZ)/5)
```

The user would then modify "nx, ny, nz" as per the dimensions required for the model being developed.

An example grid is presented below in order to assist the user in understanding the definitions of nx, ny and nz.



The above "hydrodynamic/water quality grid" has 15 cells in the x-direction, 6 cells in the y-direction and 8 vertical layers.

After editing RCACM, the user should copy the appropriate TUNER.f kinetic subroutine to the CODE directory and compile and build an executable version of RCA using either of the following commands:

df /exe:rca_ver3 /convert:BIG_ENDIAN *.f for a WINDOWS version of RCA -or- **makerca** for a LINUX (UNIX) version of RCA.

1.3 RCA File Structure

During the course of execution RCA requires a number of input files and generates a number of output files. These are briefly described in Table 2. Further details concerning these files will be provided in the following section.

TABLE 2. RCA FILE STRUCTURE

A. USER CREATED INPUT FILES

	NAME	TYPE	CONTENTS
1.	stdin	ASCII	basic input required to run the water quality model
2.	gcm_geom	BINARY	geometry as supplied from the ECOMSED hydrodynamic model
3.	wet_grid	BINARY	row, column (I,J) locations of the water segments in the hydrodynamic model
4.	hydfilna	BINARY	transport terms as supplied from the hydrodynamic model (this is the ECOMSED gcm_tran file)
5.	dffilna	BINARY	diffuser (or outfall) locations and discharge values as supplied from the hydrodynamic model
6	bcfilna	ASCII/binary	boundary condition concentrations for each system
7	psfilna	ASCII/binary	point source loads for each system
8	npsfilna	ASCII/binary	nonpoint source loads for each system
9	flfilna	ASCII/binary	fall-line loads for each system
10	atmfilna	ASCII/binary	atmospheric loads for each system
11	pcfilna	ASCII/binary	model parameters, constants and time-functions as required by the TUNER kinetic subroutine
12	icfilna	ASCII/binary	initial conditions for each system
13	sedfilna	ASCII	input required for applications involving sediment flux models

B. MODEL GENERATED OUTPUT FILES

	NAME	TYPE	CONTENTS
1.	stdout	ASCII	standard output containing all the input information and computed values as selected by the user
2.	RCAF10	BINARY	the system bypass options and times at which the grid-wide dumps were generated
3.	RCAF11	BINARY	a time-history of the grid-wide or global dumps for all state-variables
4.	RCAF12	BINARY	system bypass options, dump variable names and times at which the detailed dumps were generated (for selected segments)
5.	RCAF13	BINARY	a more-detailed time-history dump for selected segments and selected parameters
6.	RCAFIC	BINARY	concentration profiles to be used for multi-year, multi-month, etc. running (provides a "hot start" capability)

TABLE 2. RCA FILE STRUCTURE, Continued

7.	RCAF14	BINARY	the concentrations and fluxes computed by the sediment nutrient flux subroutine, if invoked by the user
8.	RCAFICSED	BINARY	concentration profiles for the sediment for multi-year running (provides a "hot start" capability), if the sediment nutrient flux subroutine is invoked by the user
9.	RCAFMB	BINARY	a time history of mass balance and flux balance terms for the water column
10.	RCAFMBSED	BINARY	a time history of mass balance and flux balance terms for the sediment nutrient flux subroutine

Appendix D provides greater detail as to the "structure" of the RCA output files.

2.0 RCA Model Input Data Description

The inputs required by RCA have been organized into a number of Input Groups and in turn into a number of input files. Table 3 presents the major input groups and associated files (there is a main input file and a number of associated input files):

TABLE 3. LISTING OF MAJOR INPUTS TO RCA BY GROUP

Input Group	File	Description
A	stdin	model descriptor information
B	stdin	print control and integration history
C	stdin	hydrodynamic time breaks and scale factors
D	stdin	names of data files to be used for the input of: boundary conditions; point source loads; nonpoint source loads; fall-line loads; atmospheric loads; parameters, constants and time functions; and initial conditions
E	stdin	stability and accuracy criteria
F	stdin	end of simulation dumps
G	bcfilna	boundary conditions
H	psfilna	point source loads
I	npsfilna	nonpoint source loads
J	flfilna	fall-line loads
K	atmfilna	atmospheric loads
L	pcfilna	parameters, constants and time functions
M	icfilna	initial conditions

GROUP A: MODEL DESCRIPTORS (STDIN)

One of the major changes in the input structure of RCA input files between Version 2 and Version 3 of the model code is that now RCA requires a comment or title record to be placed before all input records. If the user should so choose, he or she may use the comment line to indicate the variables to be read on the following record. See below for an example.

Inputs required for this group include:

1. linked run option, model listing options, and model execution options
2. model title and run description
3. water quality state-variable names
4. system by-pass options

A1. Linked Run Option, Model Listing Options and Model Execution Options

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60	70	80
CYCLE	LIST1	LIST2	LIST3	LIST4	LIST5	IDIAGDT	INPCHCK
FORMAT(10I10)							

CYCLE = linked run option (permits the user to link sequential or multiple year runs together)
= 0, model grid initial conditions are read from the icfilna input file (this is equivalent to a cold-start)
= 1, model grid initial conditions are read from the RCAFIC file, which has been generated by a previous execution of RCA (this is equivalent to a hot-start)

LIST1 = geometry (segment volumes) and transport (flow and dispersion) list option
LIST2 = boundary conditions list option
LIST3 = loadings list option
LIST4 = parameters, constants and time functions list option
LIST5 = initial conditions list option
LIST# = 0, do not list input

= 1, list input

IDIAGDT = execution option
= 0, perform RCA model run
= 1, just run through input deck to determine critical integration timesteps

INPCHCK = input checker option
= 0, perform RCA model run
= 1, just read through input deck to check for input errors

CYCLE should always be equal to 0 for a user's first run and then may be optionally set equal to 1, if the user is performing multi-year (multi-month, etc.) runs using multiple hydrodynamic transport files (gcm_tran). In order to reduce disk storage utilization, it is recommended that the user set LIST# equal to 0 unless performing verification of model inputs.

IDIAGDT can be set equal to 1 on the initial model run in order to determine the critical detention time (and, therefore, maximum timestep size for explicit integration) of the model. Should the user select the split-timestep integration algorithm, setting IDIAGDT will provide useful information for setting both critical and regular timestep sizes. Subsequently, the user would set IDIAGDT to 0 in order to perform full model simulations.

The user should set INPCHCK = 1 the first time running a new input deck to permit RCA to identify any input errors. After an input deck is read without errors, the user can set INPCHCK = 0 and proceed to perform a model simulation.

An example of the use of the "Comment" record and actual input record follows:

CYCLE	LIST1	LIST2	LIST3	LIST4	LIST5	IDIAGDT	INPCHCK
0	0	1	0	0	0	0	1

A2. Model Title and Run Description

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

80
TITLE

FORMAT (A80)

TITLE = user specified title or run description

The user may specify as many lines as desired for the title and/or run description. This input is terminated when RCA encounters a record with "END" or "end" in columns 1-3. For example:

LISS 3.0 Long Island Sound Study - 3-D Version
Uses NOAA Hydrodynamic Files Received 12/04/90
Algal Growth Rates = 2.0 and 0.9 /day Low Grazing Pressure
Recycle Rates = 0.05 /day Algal settling is a function of nutrient status
Base settling rate = 0.5 m/day - nutrient depleted settling rate = 0.5 m/day
END

A3. State-Variable Names

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

8	16	24	80
SYNAME(1)	SYNAME(2)	SYNAME(3) - - -	SYNAME(NOSYS)

FORMAT(10A8)

SYNAME(ISYS) = user specified header to describe system ISYS (NOSYS is the total number of systems or state-variables in the water quality model)

Note: Although these system names are not used explicitly in RCA, they will be used when printing input data associated with loads, boundary conditions, and initial conditions. The order of the system names is determined by the user's kinetic subroutine (TUNER).

A4. System Bypass Options

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

2	4	6	80
SYSBY(1)	SYSBY(2)	SYSBY(3) - - -	SYSBY(NOSYS)

FORMAT(40I2)

SYSBY(ISYS) = system bypass option for system ISYS
= 0, include this system in the model computation
= 1, bypass this system in the model computation

The system bypass option permits the user to include or exclude water quality variables from the model computation without performing major revisions to the user supplied inputs. The user should, however, make sure that the TUNER kinetic subroutine is written in such a way as to permit the by-passing or exclusion of the selected state-variables.

GROUP B: PRINT CONTROL AND INTEGRATION CONTROL INFORMATION (STDIN)

Inputs required for this group include:

1. integration solution options,
2. time-warp scale factor and start of simulation time,
3. number of integration step-sizes,
4. integration step-size history,
5. global and detailed print intervals and number of segments for detailed dumps,
6. segments for which detailed dumps are to be saved,
7. intermediate dump segments,
8. by-pass options for detailed dumps.
9. mass balance/flux balance options

B1. Integration Procedure Solution Options

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50
INTGRTYP	NEGSLN	SLCOPT	ISMOLAR	ISMOLBCOPT

FORMAT(5I10)

INTGRTYP = integration procedure to be used for the simulation
- = 1, explicit integration algorithm
- = 3, split-time step algorithm
- = 4, explicit integration using Smolarkiewicz corrector
- = 5, leap-frog with Smolarkiewicz corrector
- = 6, split-timestep with Smolarkiewicz corrector

(Note: options 3 and 6 are available only in the in-house version of RCA)

NEGSLN = option to permit the computation of negative concentrations
- = 0, restrict concentrations to the positive plane (normal option)
- = 1, permit the integration procedure to compute negative concentrations - used for special applications such as computing DO deficit or computing pH/alkalinity

SLCOPT = option for sigma-level correction for horizontal diffusion
- = 0, no corrections will be applied
- = 1, the sigma-level correction algorithm will be applied when computing horizontal fluxes

ISMOLAR = option for Smolarkiewicz correction
= 0, use 2nd order accurate Smolarkiewicz scheme
= 1, use recursive Smolarkiewicz scheme

ISMOLBCOPT = option for applying Smolarkiewicz correction schemes at boundaries
= 0, do not apply Smolarkiewicz scheme at boundaries
= 1, apply Smolarkiewicz scheme at boundaries

Normally, the user should select from either the explicit (INTGRTYP = 1 or 4) or the split-timestep algorithms (INTGRTYP=3 or 6) and positive solutions only (NEGSLN=0) options. Generally, by using the split-timestep option, the user can specify bigger timesteps for most segments within the model grid (only integrating a few critical segments with a small timestep) then could be chosen for explicit integration. It is strongly recommended that users not use option 5 for the reasons described previously. Usually either option 4 or 6 should be selected so as to reduce numerical dispersion (but at some cost in computational burden). The user can always evaluate the impact of numerical dispersion by running the model with and without Smolarkiewicz corrections and then comparing runs. For debugging purposes the user may wish to select INTGRTYP=1. When INTGRTYP is set equal to 1, the user may, for a particular segment, directly compute all of the terms of the derivative and compute the expected concentration at the next time level, via Equation 4:

$$c_i^{n+1} = c_i^n + \Delta t \left(\Sigma Q_{ji} c_j^n + \Sigma R_{ji} c_j^n - \Sigma \left(Q_{ik} + R_{ik} \right) c_i^n + W_i + K_i V_i c_i^n \right) \quad (4)$$

where superscripts denote time levels in the integration and subscripts denote the model grid cells or segments.

The user should be aware that if NEGSLN is set equal to 0 and RCA computes a negative concentration for a segment (or group of segments) for a time-step, RCA will not let the concentration go negative. Rather, RCA will set the concentration for the next time-step to one quarter of the old concentration. Since this, in effect, results in adding mass to the system, RCA will print a warning message. If the number of occurrences of this corrective action is small and/or the mass being added to the system is small the user should not be too concerned. If, however, the number of warning messages and/or the mass being added to the system is large, the user should rerun the simulation using smaller time-steps for the critical period.

The choice of a value for ISMOLAR should be guided by experience and side-by-side comparisons. Generally use of the recursive version of the Smolarkiewicz corrector (ISMOLAR=1) provides for greater numerical accuracy, but at a cost of 30-50 percent increase in simulation run time. It may be possible to utilize the 2nd order accurate form of Smolarkiewicz (ISMOLAR=0) and reduce simulation run times, but the user should perform simulations using both options and compare results to see if the differences between schemes are acceptable.

The choice of applying either Smolarkiewicz correction scheme at the boundary should also be guided by experience and the frequency and quality of boundary condition data. For example, in tidal systems if data are only available on a monthly basis, it is probably better not to use Smolarkiewicz corrections at the boundary. If, however, for a tidal system where boundary conditions can be specified from hourly data (i.e., from continuous recorders) or from another model (as in the case of nested-models) the use of a Smolarkiewicz correction algorithm may be appropriate.

B2. Sigma-Level Correction Parameters (SLCOPT = 1)

A sigma-level grid may result in some undesired mixing in regions of steep topography. In some cases where the layers follow the river bottom or sea-bed of the water body, adjacent segments in the same layer can lie at significantly different depths in the vicinity of steep gradients. Because of this, "horizontal" diffusion between adjacent segments can result in an artificial vertical diffusion.

The numerical error caused by this can be reduced by using a correction method based on horizontally averaged concentrations. This method involves calculating the domain averages at user-specified standard depths, and performing horizontal mixing calculations using the divergence from the average instead of the actual concentration.

It is not necessary to specify the surface level (i.e., depth = 0) when specifying the standard level depths. If the surface depth is not specified, constituent values associated with the first sigma level are used for the surface values. To ensure proper interpolation from the standard levels back to the sigma levels, each bottom sigma level must be bracketed by two standard levels, i.e., it is required to specify a standard level depth greater than the maximum expected depth in sigma-level space.

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
IDTSLCSECS	TWARPSLC	NOSLC

FORMAT (FI10, 6X,A4,I10)

IDTSLCSECS = time interval between corrections (days)
TWARPSLC = time-warp or units used for IDTSLC. Normally IDTSLCSECS is in units of seconds. The user may, however, use different units.
= SECS or secs
= MINS or mins

NOSLC = number of standard levels

10	20		80
SLCDPTH(1)	SLCDPTH(2)	···	SLCDPTH(NOSLC)

FORMAT (8F10.0)

SLCDPTH = standard-level depths

B3. Time Warp Scale Factor, Start of Simulation Time and Integration Interval for Kinetic Subroutine

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
TWARP	TZERO	IDTWQ

FORMAT(6X,A4,F10.0,I10)

TWARP = scale factor for integration step-size information. Normally the units for the general integration step-size, DT, and the kinetics integration step-size IDTWQ are seconds. However, the user may change the units of the input via TWARP.
= SECS or secs, DT and IDTWQ are read in seconds,
= MINS or mins, DT and IDTWQ are read in minutes,
= HRS or hrs, DT and IDTWQ are read in hours.

TZERO = prototype time for start of the simulation (days). Usually TZERO is set equal to 0.0, however, the user may start the simulation at a time greater than zero. For example, the user may wish to skip computing the winter months of a eutrophication model during the early calibration effort in order to reduce computer requirements. If the user has defined time equal to zero as January 1st and wishes to start the simulation in early May, TZERO would be set equal to 120. RCA would then ensure that all time-dependent inputs are at their proper starting values before initiating the simulation.

IDTWQ = integration interval for the kinetic subroutine (nominally in seconds). If IDTWQ = 0, RCA will integrate the kinetic portion of the derivative at the same timestep as used for the transport (see Card Group B4 below). If IDTWQ> 0, then the kinetic subroutine, TUNER, will be called every IDTWQ

seconds. The latter implies that the kinetic portion of the derivative is assumed to be constant over the interval IDTWQ. (Note: the user should ensure that the value chosen for IDTWQ should be an exact multiple of any value of ISTEP or IDTSPLIT - see below).

The following inputs (B4 and B5) are required for INTGRTYP = 1, 4 or 5

B4. Number of Integration Step-Sizes (INTGRTYP = 1, 4, or 5)

For a number of water quality problems, there may be periods of time within the simulation period for which small integration steps are required (ex. during storm runoff events or spring snowmelt) versus times when larger timesteps can be used (ex. summer low flow). Therefore, RCA permits the user to specify a time-variable history of integration stepsizes to be used during the simulation.

```
                80
          Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10
       NSTEP
FORMAT(I10)
```

NSTEP = number of integration step-sizes to be read

B5. Integration Step-Size History (INTGRTYP = 1, 4, or 5)

```
                80
          Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
      10        20        30        40                  70                80
ISTEP(1)  TBRK(1)  ISTEP(2)  TBRK(2)  - - - ISTEP(NSTEP)  TBRK(NSTEP)
FORMAT (4(I10,F10.0))
```

ISTEP(I) = integration step-size (seconds)
TBRK(I) = time (days) until which ISTEP(I) is to be used, then switching to ISTEP(I+1) until TBRK(I+1)

The default units for ISTEP are seconds. However, if TWARP is specified as minutes, hours, or days then values for ISTEP will be in the same units as specified by TWARP. (Note: the value of ISTEP(I) should be an exact divisor of TBRK(I) for each ISTEP/TBRK pair and all ISTEP/TBRK pairs must be an exact divisor of IHYDDT - see C2 below).

The following input (B6) is required for INTGRTYP = 3 or 6

B6. Integration Stepsizes and Total Simulation Time (INTGRTYP = 3 or 6)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
IDTSPLIT	IDTFULL	TEND

FORMAT (2I10,F10.0)

IDTSPLIT = timestep to be used for the "high speed" or "critical" timestep segments (seconds)
IDTFULL = timestep to be used for remaining segments (seconds)
TEND = total simulation time, in days

The default units for IDTSPLIT and IDTFULL are seconds. However, if TWARP is specified as minutes, hours, or days then values for IDTSPLIT and IDTFULL will be in the same units as specified by TWARP. (Note: IDTSPLIT should be an exact divisor of IDTFULL and both IDTSPLIT and IDTFULL need to be an exact divisor of IHYDDT - see C2 below).

B7. Print Control Information

RCA permits two types of output dumps to be generated: global or domain-wide dumps at "coarse" time intervals, and detailed or selected segments at "fine" time intervals. By global dumps it is meant that the concentrations of all systems for all segments (i.e. all x, y, and z) are saved at the print interval, IPRNTG, described below. A note of caution: if a user has a 100 x 100 grid with 10 depth levels and 25 systems, a total of 10 Mbytes will be written at every IPRNTG interval. Clearly, one should not generate global dumps every day for a one year simulations (unless one has a disc storage system with large capacity).

However, in order to permit the user to generate daily (or hourly) output if necessary an option has been included in RCA to permit the user to select a number of segments

for which information will be stored at a finer interval, IPRNTD, than is used for global dumps.

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60
IPRNTG	IPRNTD	NDMPS	TWARPP	IGDOPT	IDDOPT

FORMAT (3I10,6X,A4,2I10)

IPRNTG = time interval (default = seconds) for saving "global" (or grid-wide) concentrations,

IPRNTD = time interval (default = seconds) for saving "detailed" (or segment specific) concentrations and rate terms as per the user kinetic subroutine,

NDMPS = number of selected segments to be used in generating detailed dumps if IPRNTD≠0

TWARPP = units in which IPRNTG and IPRNTD are input. Acceptable units for IPRNTG and IPRNTD are SECS (seconds), MINS (minutes), HRS (hours), or DAYS (days) and may be entered in either upper or lower case.
So, for example, a user who wished to get detailed dumps at one day intervals could specify IPRNTD = 86400, TWARPP = SECS or IPRNTD = 1, TWARPP = DAYS.

IGDOPT = global dump averaging option
- = 0, write instantaneous (i.e., no averaging) concentrations or rates
- = 1, write "averaged" concentrations or rates, using IPRNTG as the averaging interval

IDDOPT = detailed dump averaging option
- = 0, write instantaneous (i.e., no averaging) concentrations or rates
- = 1, write "averaged" concentrations or rates, using IPRNTD as the averaging interval

B8. Segments for which Detailed Dumps are to be saved
(Note: if IPRNTD = 0 or NDMPS = 0) skip this group and continue with B9.)

```
                    80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          4         8         12                  72
IFDMPS(1,1) IFDMPS(1,2) IFDMPS(1,3) ---  IFDMPS(NDMP,3)
FORMAT (18I4)
```

IFDMPS(I,1) = X, Y and Z location designations, respectively, for the desired segments to be saved
IFDMP(I,2)
IFDMP(I,3)

B9. System Bypass Options for Detailed Dumps

```
                    80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          2         4                  80
DDMPBY(1) DDMPBY(2) --- DDMPBY(NOSYS)
FORMAT(40I2)
```

DDMPBY(ISYS) = system bypass options for making detailed dumps
= 0, include this system when making detailed dumps
= 1, do not include this system when making detailed dumps

This option permits the user to generate detailed dumps for a system even if that system is being bypassed (SYSBY=1) in the overall model computation. The major reason for including this option is so that users do not need to modify their GDP command decks if systems on being turned on and off during the calibration process. Of course, the user can also bypass making detailed dumps for a system (by setting DDMPBY=1), even if the system is being computed. However, the user should be sure to check whether the kinetic subroutine TUNER has been written in such a way as to make this input option function properly.

B10. Segments to be Displayed for Intermediate Dumps

RCA permits the user to monitor the progress of the water quality simulation by dumping the concentrations of six segments to the screen (or the user's output file with

access via the UNIX/LINUX "tail" command) at each print interval during the simulation.

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

4	8	12	16	20	24		64	68	72
IX (1)	IY(1)	IZ(1)	IX (2)	IY(2)	IZ(2)	---	IX (6)	IY(6)	IZ(6)

FORMAT(18I4)

IX,IY,IZ = X, Y and Z IDs of segments to be displayed during the simulation.

B11. Mass Balance - Mass Flux Computation Options

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60
MASSBAL	IPRNTMB	TWARPMB	IMBOPT	ISTARTMB	IENDMB

FORMAT (2I10,6X,A4,3I10)

MASSBAL = mass/flux balance computation option
= 0, do not perform mass or flux balance computations
= 1, perform mass and flux balance computations

IPRNTMB = print interval (default = seconds) for saving mass balance and flux balance computations

TWARPMB = units in which IPRNTMB, ISTARTMB, and IENDMB are input. Acceptable units are SECS (seconds), MINS (minutes), HRS (hours), or DAYS (days).

IMBOPT = mass/flux balance dump averaging option
= 0, dump instantaneous (i.e., no averaging) mass balance and flux balance computations
= 1, dump "averaged" mass balance and flux balance computations, using IPRNTMB as the averaging interval

ISTARTMB = starting time (default = seconds) for beginning mass balance/flux balance computations

IENDMB = ending time (default = seconds) for performing mass balance/flux balance computations

This option permits the user to perform domain-wide mass/flux balance computations. The model output can be used to assess the importance of boundary inflows/outflows versus point, non-point, and atmospheric inputs, as well as to perform system-wide mass balance checks.

When selecting a "print interval" for applications in estuarine systems, it is recommended to select a print interval that is an exact multiple of a tidal cycle (44712 seconds or 12.42 hours). If one selects a non-tidal print interval it may make interpretation of flux balance results more difficult since the model would be outputting flux balances that occur over different parts of the tidal cycle and thus, for example, on a flood tide the model output would reflect a net import of mass into the model domain, while output on an ebb tide would reflect a net export of mass from the model domain. It is possible then in a tidal system where there is a small net export of mass from the domain that the flux balance would show a net import of mass if one were to start the flux balances at mean tide or mean tidal elevation but end the simulation at maximum flood tide. The user can also specify the starting and ending times, ISTARTMB and IENDMB, respectively, to help overcome this potential problem. (Example: if one were to perform a 365 day simulation, one could set ISTARTMB = 0 and then specify IENDMB = 31521960 seconds = 364.8375 days and the model will end at the same point in the tidal cycle.)

GROUP C: HYDRODYNAMIC TIME BREAKS AND SCALE FACTORS (STDIN)

Inputs required for this group include:

1. hydrodynamic file input options
2. time breaks for the hydrodynamic fields
3. flow and dispersion scale factors
4. file name containing the ECOMSED hydrodynamic fields

C1. Hydrodynamic File Input Options

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40
ICOLLOPT	HYDCYCOPT	LNDWTROPT	IDIFFOPT

FORMAT(4I10)

ICOLLOPT = option to inform RCA whether the gcm-geom and gcm_tran have been grid collapsed (i.e., the water quality model is a collapsed or aggregated version of the hydrodynamic grid)
- = 0, no grid collapse was performed
- = 1, grid collapse was performed

HYDCYCOPT = option to permit RCA to "cycle" or repeat the "gcm_tran" file, i.e. hydrodynamics are at periodic steady-state
- = 0, do not "cycle" hydrodynamics if end-of-file encountered
- = 1, "cycle" hydrodynamics, i.e., go back to beginning of the hydrodynamic file if end-of-file encountered

LNDWTROPT = option to select whether full-grid (land/water) hydrodynamic input to be read or just water cells
- = 0, full-grid, i.e., land and water
- = 1, just water cells (requires "wet-grid" input file from ECOMSED)

IDIFFOPT = option to specify and read "diffuser" files generated by ECOMSED
- = 0, no diffuser files specified
- = 1, diffuser files will be specified

The use of the HYDCYCOPT options permits users to perform water quality simulations for periods of time longer than the hydrodynamic model was run. For

example, suppose a user wanted to run a 10 day simulation of a dye release into a tidal creek, subject to no freshwater inflow and with a constant tidal amplitude. The user could run the hydrodynamic model and save 10 days of periodic stage and velocity and set HYDCYCOPT = 0 , or just run the hydrodynamic model for one tidal cycle and save just one tidal cycle worth of stage and velocity and set, HYDCYCOPT = 1. RCA would go back to the beginning of the gcm_tran file (recycle) when the simulation time reached tidal cycle 1, 2, (day) etc. (Note: The use of HYDCYCOPT = 1 assumes that the hydrodynamics are at periodic steady-state.)

C2. Time Breaks for the Hydrodynamic Fields

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
IHYDDT	UNITS

FORMAT(I10,6X,A4)

IHYDDT = averaging period used by ECOMSED to save hydrodynamic output (nominally in secs).

UNITS = time-warp or units used for IHYDDT. Normally IHYDDT is input in units of seconds. The user may, however, use different units:

= SECS or secs, IHYDDT is read in seconds,
= MINS or mins, IHYDDT is read in minutes,
= HRS or hrs, IHYDDT is read in hours.

C3. Dispersive Scale Factors

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
SCALRX	SCALRY	SCALRZ

FORMAT(3F10.0)

SCALRX = scale factor to multiply all horizontal or x-direction dispersion coefficients by

SCALRY = scale factor to multiply all lateral or y-direction dispersion coefficients by

SCALRZ = scale factor to multiply all vertical or z-direction dispersion coefficients by

Normally, SCALRX, SCALRY and SCALRZ should be set equal to 1.0.

C4. The Number of Hydrodynamic and Diffuser Files

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOHYDFILNA

FORMAT (I10)

NOHYDFILNA = number of hydrodynamic and diffuser (if supplied by ECOMSED) files to be used in this simulation (maximum of 36)

C5. The Names of the Files Containing the Hydrodynamic and Diffuser Transport Fields

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

40	80
HYDFILNA	DIFFILNA

FORMAT(2A40)

HYDFILNA = complete path length and file name containing the ECOMSED transport and surface elevation data (gcm_tran)

ex.1 /usersb/neng0010/HYDRO/gcm_tran
ex.2 ../HYDRO/hydro.84
ex.3 ../HYDRO/hydro.85
(Note: the use of a "/" to specify the path or directory structure for a file is consistent with UNIX or

LINUX file naming structure. Running RCA under a WINDOWS environment means, of course (thanks to Bill Gates), using "\".

DIFFILNA = complete path length and file name containing the ECOMSED diffuser (or outfall) discharge information (gcm_gdiff).

GROUP D: INPUT FILE NAMES (STDIN)

Inputs required for this group include:

1. the name of the file to be used to read boundary conditions inputs
2. the name of the file to be used to read point source loading inputs
3. the name of the file to be used to read nonpoint source loading inputs
4. the name of the file to be used to read fall-line loading inputs
5. the name of the file to be used to read atmospheric loading inputs
6. the name of the file to be used to read parameters, constants, miscellaneous time-variable functions and file names of miscellaneous files required by the users kinetic subroutine
7. the name of the file to be used to read initial conditions

RCA has been programmed so as to permit the user to develop a number of subfiles that contain RCA required inputs, rather than have all of the model input contained in one large input file as is done in AESOP. The reason for this is to provide the user with an extra degree of flexibility in generating model input files. If, for example, the user wishes to evaluate model response to a specific waste discharger, the user can set up two point source loading files, one with the discharger's load included and one with it not included. The user would then edit the standard input (STDIN) file and change the file name associated with the point source loadings (specified by D2) to the appropriate external point source file and then execute RCA. Since the standard input file (consisting of various input options for integration and printout histories and file names for the aforementioned RCA inputs) is so small, the time spent in editing should be very short. In addition, having various input groups permits users to develop a number of utility programs to generate the relevant input files rather than have one large complicated program to generate the entire input file at one time.

Further, as an option, the boundary condition, point source, etc. files may be read in either ASCII or binary (to save disc space) format. Binary format, of course, means that another FORTRAN program or utility must be used to generate the file. For binary files the user SHOULD NOT include the "comment" records in his or her input file.

New to RCA 3.0 is the option to bypass a particular file by specifying "NULL" or "null" (without the quotes) in the first four spaces. For example, if a particular application has no fall-line loads, the user just has to specify "NULL" for FLFILNA instead of having to create a dummy fall-line loads file with no loads.

D1. The Name of the File to be Used to Read Boundary Conditions Inputs, Binary Read Option

```
                80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
      40          50
BCFILNA   IBNRYOPT
FORMAT(A40, I10)
```

BCFILNA = complete path length and file name containing the boundary condition information (i.e., boundary segments and concentrations)

ex.1 /usersb/neng0010/HYDRO/boundcond (input file named "boundcond" resides in the /usersb/neng0010/HYDRO directory)

ex.2 bc.file (input file name bc.file resides in the current directory)

ex.3 ../inputs/bc.84 (input file named bc.84 resides in the inputs directory, which is a subdirectory of the directory one level above the currect directory

= NULL to bypass this file. The appropriate vectors will be set to zero.

IBNRYOPT = option telling RCA to read ASCII or binary formatted boundary condition file

= 0, read ASCII file

= 1, read binary file

D2. The Name of the File to be Used to Read Point Source Loading Inputs, Binary Read Option

```
                80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
      40          50
PSFILNA   IBNRYOPT
FORMAT(A40,I10)
```

PSFILNA = complete path length and file name containing the point source loading information (loading segments and point source loads)
= NULL to bypass this file. The appropriate vectors will be set to zero.

IBNRYOPT = option telling RCA to read ASCII or binary formated file
= 0, read ASCII file
= 1, read binary file

D3. The Name of the File to be Used to Read Nonpoint Source Loading Inputs, Binary Read Option

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

40 50
NPSFILNA IBNRYOPT
FORMAT(A40,I10)

NPSFILNA = complete path length and file name containing the nonpoint source loading information (loading segments and nonpoint source loads)
= NULL to bypass this file. The appropriate vectors will be set to zero.

IBNRYOPT = option telling RCA to read ASCII or binary formated files
= 0, read ASCII file
= 1, read binary file

D4. The Name of the File to be Used to Read Fall-line Loading Inputs, Binary Read Option

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

40 50
FLFILNA IBNRYOPT
FORMAT(A40,I10)

FLFILNA = complete path length and file name containing the fall-line loading information (fall-line segments and fall-line loads)
= NULL to bypass this file. The appropriate vectors will be set to zero.

IBNRYOPT = option telling RCA to read ASCII or finary formatted file
= 0, read ASCII file
= 1, read binary file

D5. The Name of the File to be Used to Read Atmospheric Loading Inputs, Binary Read Option

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

40 50
ATMFILNA IBNRYOPT
FORMAT(A40,I10)

ATMFILNA = complete path length and file name containing the atmospheric loading information (amtospheric loads)
= NULL to bypass this file. The appropriate vectors will be set to zero.

IBNRYOPT = option telling RCA to read ASCII or binary formated file
= 0, read ASCII file
= 1, read binary file

D6. The Name of the File to be Used to Read Parameters, Constants, Time-Variable Functions and Miscellaneous File Names, Binary Read Option

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

40 50
PCFILNA IBNRYOPT
FORMAT(A40,I10)

PCFILNA = complete path length and file name containing the parameters, constants and time-variable functions

= NULL to bypass this file. The appropriate vectors will be set to zero.

IBNRYOPT = option telling RCA to read ASCII or binary formatted files
= 0, read ASCII file
= 1, read binary file

D7. The Name of the File to be Used to Read Initial Conditions, Binary Read Option

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

40 50
ICFILNA IBNRYOPT
FORMAT(A40,I10)

ICFILNA = complete path length and file name containing the initial conditions

IBNRYOPT = option telling RCA to read ASCII or binary formatted files
= 0, read ASCII file
= 1, read binary file

GROUP E: STABILITY AND ACCURACY CRITERIA (STDIN)

E1. Stability Criteria

```
         80
    Comment
FORMAT(A80)
```

Comment = Comment line (ignored by RCA)

```
      20        30                  80
CMAX(1)  CMAX(2)  - - -  CMAX(NOSYS)
FORMAT(10X,7F10.0)
```

CMAX(ISYS) = stability criteria for system ISYS, i.e. a maximum concentration that if exceeded in any segment or grid cell indicates that the numerical integration procedure has become unstable. If an instability occurs an appropriate error message is written and the simulation is terminated.

E2. Minimum Concentrations for Numerical Integration

```
          80
     Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
      20        30                  80
CMIN(1)  CMIN(2)  - - -  CMIN(NOSYS)
FORMAT(10X,7F10.0)
```

CMIN(ISYS) = the minimum concentration or "floor" for system ISYS. As was mentioned earlier, under the description of the input variable NEGSLN, RCA normally does not permit negative solutions to occur. It does this by "quartering" concentrations. If, however, enough "quartering" of concentrations occur in a segment, underflows (i.e., concentrations less than 1.0E-38) may occur, which will result in the RCA run terminating. To prevent this the user should specify minimum values which will limit the "quartering" process. Recommended values for CMIN are 1.0E-20.

GROUP F: END OF SIMULATION DUMPS (STDIN)

Inputs from this group are read at the end of a simulation run.

F1. System Dumps

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

At the completion of the simulation the user may wish to display or dump the concentrations of any or all segments for any or all systems. The following inputs are read for each global dump saved starting with the first and going through system dump = NGDMP (where NGDMP is set in the users kinetic subroutine).

3	6	9	12		69	72	75		78	80
IVAR	IX(1)	IY(1)	IZ(1)	- - -	IX(8)	IY(8)	IZ(8)	LYRDMP		LYR

FORMAT(I3,24I3,A3,I2)

IVAR = 1, for global system dumps (Note: currently only the state-variable concentrations are available for dumping, hence IVAR = 1. However, in the future, RCA may permit IVAR may take on other values.)

IX,IY,IZ = x, y and z designation for the segment to be displayed

LYRDMP = if LYRDMP is read in as "LYR" then all segments within a particular layer (for layer = LYR) will be displayed without the user being required to specify each IX,IY,IZ combination

LYR = the layer for which concentrations are to be dumped (if LYRDMP is read as "LYR")

Table 4 presents an example of the STDIN input file for Groups A through F.

TABLE 4. EXAMPLE OF STANDARD INPUT FILE - STDIN

```
C    Cycle List_Geom  List_BCs  List_WKs  List_PCs  List_ICs   IDIAGDT    INPCHK
        0         0         0         0         0         0         0         0
C    Model Run Descriptor Comments Follow (Terminate with an "END")
  MERL Tank Simulation
  Input set up to simulate Control Tanks 0 - 5 - 8
END
C    System Names (1 ... NOSYS)
     SAL    PHYT1    PHYT2     RPOP     LPOP     RDOP     LDOP      DIP     RPON     LPON
    RDON     LDON      NH3     NO23      SIU       SI     RPOC     LPOC     RDOC     LDOC
   REDOC    EXDOC    O2EQ       DO
C    Type of Simulation
TIME-VARIABLE SIMULATION
C    System By-pass Options (1 ... NOSYS)
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
C INTGRTYP    NEGSLN    SLCOPT   ISMOLAR ISMOLBCOP
        1         0         0         0         0
C    TWARP     TZERO IDTWQSECS
      MINS       0.0         0
C    NSTEP
        1
CIntg_Step UntilTime Intg_Step UntilTime Intg_Step UntilTime Intg_Step UntilTime
        72      109.     1090.
C    PRNTG     PRNTD     NDMPS    TWARPP    IGDOPT    IDDOPT
       240       240         3       HRS         0         0
C    Detailed Dumps (IR,IC,IL)  (1 ... NDMPS)
   2   2   1   2   2   2   1   1
C    Detailed Dump By-pass Options (1 ... NOSYS)
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
C    Intermediate Dumps (IR,IC,IL)  (1 ... 6)
   2   2   1   2   2   2   2   2   1   2   2   2   2   2   1   2   2   2
C  MASSBAL   IPRNTMB   TWARPMB    IMBOPT ISTARTMB    IENDMB
        1    447120      SECS         0        0  31521960
C ICOLLOPT HYDCYCOPT LNDWTROPT
        0         0         1      non-collapsed, non-split hydro files,water only
C   IHYDDT     UNITS
       720       HRS
C   SCALRX    SCALRY    SCALRZ
       1.0       1.0     1.000
C   Number and Names of Hydrodynamic Files
        2
gcm_tran_1-6
gcm_tran_7-12
C    Boundary Condition File Name      Binary Read Option
bc058.inp
C    Point Source Loads File Name      Binary Read Option
NULL
C    Non-point Source Loads File Name  Binary Read Option
NULL
C    Fall-line Loads File Name         Binary Read Option
fltest.inp
C    Atmospheric Loads File Name       Binary Read Option
NULL
C    Params, Consts, TVFs File Name    Binary Read Option
pctvf058.inp
C    Initial Conditions File Name      Binary Read Option
ic058.inp
C    Stability Concentrations
stability      5000.     3000.    3000.0    1000.0   100.000      20.0     50.00
              100.00     500.0    100.00    1000.0     500.0    1000.0    1000.0
              1000.0    1000.0    1000.0    1000.0    2000.0    5000.0    3000.0
              1000.0    3000.0    5000.0
C    Floor Concentrations
floor       0.000001  0.000001  0.000001  0.000001  0.000001  0.000001  0.000001
            0.000001  0.000001  0.000001  0.000001  0.000001  0.000001  0.000001
            0.000001  0.000001  0.000001  0.000001  0.000001  0.000001  0.000001
            0.000001  0.000001  0.000001
C   Selection of Simulation Dumps Follow
  1                                                                    LYR  1
  1                                                                    LYR  2
                                                                           End Sys  1
  1                                                                    LYR  1
  1                                                                    LYR  2
                                                                           End Sys  2
/*
```

GROUP G: BOUNDARY CONCENTRATIONS (BCFILNA)

The user may choose to input boundary condition information using either sigma-level specification or standard-level specification. For sigma-level specification the user enters the boundary concentrations associated with each boundary segment in the model, specifying both the (IX,IY,IZ) segment location and the average water column concentration at the appropriate model segment depth. For example, assume one is modeling a river with one upstream and one downstream boundary, using a one column wide (i.e. laterally averaged) grid and five equally spaced vertical layers. Then the model has a total of ten boundary conditions, one boundary condition for each of the five upstream layers and one for each of the five downstream layers. If the total depth of the upstream boundary is 5 meters, then the boundary conditions would be assumed to represent water quality conditions every one meter in depth. If the total depth at the downstream boundary is 15 meters, then the boundary conditions would be assumed to represent water quality conditions every three meters in depth.

For standard level specifation, the user first specifies the standard levels (or depths) at which the boundary conditions will be provided for a particular system and then specifes for each (IX,IY) boundary location the number of standard level depths for this location and the associated water column concentrations at the standard levels or depths. RCA will then interpolate (using linear interpolation) the specified standard level boundary conditions onto the sigma-level grid. Using the same river system model as above, and having water column observations only at the surface, 3 meter, 10 meter and 15 meter depths, the user would specify four standard level depths, i.e. 0, 3, 10 and 15 meters, and two boundary (IX,IY) locations (i.e., the (IX,IY) locations of the upstream and downstream boundaries). For the upstream boundary, data are available for only two standard levels, 0 and 3 meters, while for the downstream boundary the user would input water quality concentrations at the four standard levels, 0, 3, 10 and 15 meters. RCA would then interpolate the two upstream concentrations, using linear interpolation, to equivalent sigma-level depths of 0.5, 1.5, 2.5, 3.5 and 4.5 meters, and would also interpolate the four downstream concentrations onto the downstream sigma-level depths of 1.5, 4.5, 7.5, 10.5, and 13.5 meters.

Inputs required for this group include:

1. boundary condition input options
2. number of boundary conditions
3. scale factor for boundary concentrations
4. actual boundary concentrations

G1. Boundary Condition Input Option

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
IBCOPT	IBCPWLOPT

FORMAT(2I10)

IBCOPT = input option
- = 1, time-invariant (or constant) sigma-level concentrations will be read
- = 2, time-variable sigma-level boundary concentrations will be read
- = 3, time-invariant (or constant) standard level concentrations will be read
- = 4, time-variable standard level boundary concentrations will be read

IBCPWLOPT = option to select step-function or piecewise linear interpolation of time-variable boundry conditions.
- = 0, step-function interpolation will be used
- = 1, piecewise linear interpolation will be used

The remaining boundary condition input is dependent upon the IBCOPT input option chosen. Data inputs for sigma-level option 1 (constant concentrations) and option 2 (time-variable) will be presented first, followed by data inputs associated with standard level options 3 (constant concentrations) and option 4 (time-variable).

Constant or Time-Invariant Concentrations - Sigma Level (IBCOPT = 1)

Data associated with Data Types G2, G3 and G4 will be read NOSYS times; once for each system in the model.

G2. Number of Boundary Conditions

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

```
          10
NOBC(ISYS)
FORMAT(I10)
```

NOBC(ISYS) = the number of boundary conditions for system ISYS

(Note: If there are no boundary conditions to be specified for a system (NOBC = 0) then no input is required for G3 or G4; just continue with next G2.)

G3. Boundary Concentration Scale Factor

```
                  80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10
SCALBC(ISYS)
FORMAT(F10.0)
```

SCALBC(ISYS) = scale factor for system ISYS

Normally SCALBC(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in boundary inputs, SCALBC(ISYS) would then be set equal to 0.75.

G4. Boundary Segments and Boundary Concentrations

```
                  80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10          14          17          20
BBC(1,ISYS) IBC(1,1,ISYS) IBC(2,1,ISYS) IBC(3,1,ISYS)  - - -

                  70          74          77          80
   BBC(NOBC,ISYS) IBC(1,NOBC,ISYS) IBC(2,NOBC,ISYS) IBC(3,NOBC,ISYS)
FORMAT(4(F10.0,1X,3I3))
```

BBC(I,ISYS) = boundary concentration (mg/L)
IBC(1,I,ISYS) = x-cell number of boundary condition grid element

IBC(2,I,ISYS) = y-cell number of boundary condition grid element
IBC(3,I,ISYS) = z-cell or layer number of boundary condition grid element

The following example illustrates how to assign the x, y and z information required for RCA.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
2	L	OWB			L	L	L						L	L	L
3	L	OWB								L				FFI	L
4	L	OWB								L	L			L	L
5	L	OWB											L	L	L
6	L	L	L	L	L	L	L	L	FFI	L	L	L	L	L	L

The above illustration shows a 15x6 grid; NX=15 and NY=6. Grid elements denoted by an "L" indicate either a land segment or the limits of the model domain. Grid elements denoted by "OWB" indicate an open water boundary (including flow and dispersion consistent with the ECOMSED grid notation), while those represented by "FFI" represent free flowing inputs (flow only, no dispersion), such as a river/dam or an onshore outfall/intake discharge. The model also has 6 vertical layers.

The model, then, has 36 ((4 OWB + 2 FFI)*6) boundary conditions, specified as follows:

IBC(1,I,ISYS)	IBC(2,I,ISYS)	IBC(3,I,ISYS)
2	2	1
2	2	2
:	:	:
2	2	6
2	3	1
:	:	:
2	3	6
2	4	1
:	:	:
2	4	6
2	5	1
:	:	:
2	5	6
9	6	1
:	:	:
9	6	6
14	3	1
:	:	:
14	3	6

Time-Variable Concentrations - Sigma Level (IBCOPT = 2)

G2. Time for which Boundary Concentrations are being Specified

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30
NXBCTSECS	TWARPBC

FORMAT (10X,I10,6XA4)

NXBCTSECS = time in seconds (or units specified by TWARPBC)
TWARPBC = time-warp or units used for NXBCTSECS.
Normally NXBCTSECS is input in units of seconds. The user may, however, use different units.
= SECS or secs,
= MINS or mins,
= HRS or hrs,
= DAYS or days.

Data associated with Data Types G3 through G6 will be read NOSYS times; once for each system in the model.

G3. Number of Boundary Conditions

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOBC(ISYS)

FORMAT(I10)

NOBC(ISYS) = the number of boundary conditions for system ISYS

(Note: If there are no boundary conditions to be specified for a system (NOBC = 0), then no input is required for G4, G5 or G6; just continue with next G3.)

G4. Boundary Concentration Scale Factor

```
                80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
              10
SCALBC(ISYS)
FORMAT(F10.0)
```

SCALBC(ISYS) = scale factor for system ISYS

Normally SCALBC(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in boundary inputs, SCALBC(ISYS) would then be set equal to 0.75.

G5. Boundary Segments

```
                80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
            14              17              20
IBC(1,1,ISYS)  IBC(2,1,ISYS)  IBC(3,1,ISYS)   - - -

                  74                  77                  80
   IBC(1,NOBC,ISYS)  IBC(2,NOBC,ISYS)  IBC(3,NOBC,ISYS)
FORMAT(10X,7(I4,I3,I3))
```

IBC(1,I,ISYS) = x-cell number of boundary condition grid element
IBC(2,I,ISYS) = y-cell number of boundary condition grid element
IBC(3,I,ISYS) = z-cell or layer number of boundary condition grid element

G6. Boundary Concentrations

```
            20              30                              80
BBC(1,ISYS)  BBC(2,ISYS)  ---  BBC(NOBC(ISYS),ISYS)
FORMAT(10X,7F10.0)
```

BBC(I,ISYS) = boundary concentration (mg/L)

The boundary concentrations (BBC) should be specified in the same order as the x, y, and z (IBC) designations were read. After input types G3 through G6 are repeated for each system, then the simulation time at which the next set of boundary concentrations is to be read, NXBCT, is specified; followed by the next set of boundary concentrations (input type G6); it is not necessary to repeat input types G3, G4 and G5. If NOBC(ISYS) = 0 for system ISYS then the user would skip specifying G6 input data for that system.

Data associated with Data Types G3, G4, G5 and G6 will be read NOSYS times; once for each system in the model.

Constant or Time-Invariant Concentrations - Standard Level (IBCOPT = 3)

G2. Number of Boundary Conditions

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOBC(ISYS)

FORMAT(I10)

NOBC(ISYS) = the number of boundary conditions for system ISYS

(Note: If there are no boundary conditons to be specified for a system (NOBC = 0), then no input is required for G3, G4, G5, G6 or G7; just continue with next G2.)

G3. Boundary Concentration Scale Factor

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALBC(ISYS)

FORMAT(F10.0)

SCALBC(ISYS) = scale factor for system ISYS

Normally SCALBC(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in boundary inputs, SCALBC(ISYS) would then be set equal to 0.75.

G4. Number of Standard Level Depths

```
                80
        Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          5
NLVLS(ISYS)
FORMAT(I5)
```

NLVLS(ISYS) = the maximum number of standard level depths required for system ISYS

G5. Standard Level Depths

```
                80
        Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          20                  30                  80
SLDEPTH(1,ISYS)  SLDEPTH(2,ISYS) --- SLDEPTH(NLVLS,ISYS)
FORMAT(10X,7F10.0)
```

SLDEPTH(I,ISYS) = the depth of standard level I, (meters) to be used to specify boundary concentration data for system ISYS

G6. Boundary Segments and Number of Standard Levels to be Read

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

5	10	15
IBCSL(1,IBC,ISYS)	IBCSL(2,IBC,ISYS)	NOBCSL(IBC,ISYS)

FORMAT(3I5)

IBCSL(1,IBC,ISYS) = x-cell number of boundary condition segment
IBCSL(2,IBC,ISYS) = y-cell number of boundary condition segment
NOBCSL(IBC,ISYS) = number of standard level concentrations to be read for boundary condition IBC (maximum number must be less than or equal to NLVLS)

G7. Boundary Concentrations at Standard Levels

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30	80
SLBC(1,IBC,ISYS)	SLBC(2,IBC,ISYS) —	SLBC(NOBCSL,IBC,ISYS)

FORMAT(10X,7F10.0)

SLBC(I,IBC,ISYS) = boundary concentration (mg/L)

After reading in the boundary concentrations at the standard levels RCA will perform a linear interpolation of the input data onto the sigma level grid and produce a set of boundary segment numbers (IX,IY and IZ) and concentrations similiar to the input required for IBCOPT = 1.

Inputs G4, G5, G6, and G7 will be read NOBC(ISYS) times; once for each boundary condition

Time-Variable Conditions - Standard Level (IBCOPT = 4)

G2. Time for which Boundary Concentrations are being Specified

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30
NXBCTSECS	TWARPBC

FORMAT (10X, I10,6X,A4)

NXBCTSECS = time in seconds (or units specified by TWARPBC)
TWARPBC = units to be used for NXBCTSECS
= SECS or secs,
= MINS or mins,
= HRS or hrs,
= DAYS or days.

Data associated with Data Types G3 through G8 will be read NOSYS times; once for each system in the model.

G3. Number of Boundary Conditions

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOBC(ISYS)

FORMAT(I10)

NOBC(ISYS) = the number of boundary conditions for system ISYS

(Note: If there are no boundary conditons to be specified for a system (NOBC = 0), then no input is required for G4 to G8; just continue with next G3.)

G4. Boundary Concentration Scale Factor

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALBC(ISYS)
FORMAT(F10.0)

SCALBC(ISYS) = scale factor for system ISYS

Normally SCALBC(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in boundary inputs, SCALBC(ISYS) would then be set equal to 0.75.

G5. Number of Standard Level Depths

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NLVLS(ISYS)
FORMAT(I10)

NLVLS(ISYS) = the maximum number of standard level depths required to specify boundary concentration information for system ISYS

G6. Standard Level Depths

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

```
                    20                  30                              80
SLDEPTH(1,ISYS)  SLDEPTH(2,ISYS) --- SLDEPTH(NLVLS,ISYS)
FORMAT(10X,7F10.0)
```

SLDEPTH(I,ISYS) = the depth of standard level I, (meters)

G7. Boundary Segments and Number of Standard Levels to be Read

```
              80
      Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
                5                  10                  15
IBCSL(1,IBC,ISYS)  IBCSL(2,IBC,ISYS)  NOBCSL(IBC,ISYS)
FORMAT(3I5)
```

IBCSL(1,IBC,ISYS) = x-cell number of boundary condition segment
IBCSL(2,IBC,ISYS) = y-cell number of boundary condition segment
NOBCSL(IBC,ISYS) = number of standard level concentrations to be read for boundary condition IBC (maximum number must be less than or equal to NLVLS)

G8. Boundary Concentrations at Standard Levels

```
                    20                  30                              80
SLBC(1,IBC,ISYS)  SLBC(2,IBC,ISYS) —  SLBC(NOBCSL,IBC,ISYS)
FORMAT(10X,7F10.0)
```

SLBC(I,IBC,ISYS) = boundary concentration (mg/L)

After reading in the boundary concentrations at the standard levels RCA will perform a linear interpolation of the input data onto the sigma level grid and produce a set of boundary segment numbers (IX,IY and IZ) and concentrations similiar to the input required for IBCOPT = 2.

After input types G2 through G8 are read for each system, then the time of the next set of boundary concentrations, NXBCT, will be required; followed by the next set of boundary concentrations specified at standard levels (input type G8); it is not necessary to repeat input types G2 through G7.

Table 5 presents an example of a boundary condition input file using time- variable sigma level input (IBCOPT = 2), while Table 6 presents an example of a boundary condition input file using time-invariant or constant standard level input.

TABLE 5. EXAMPLE OF TIME-VARIABLE SIGMA-LEVEL BOUNDARY CONDITIONS - BCFILNA

```
C    BCOPT    PWLOPT
         2         0            base values - no additions to PO4,NH3,Si for algal biomass
C          NXBCTSECS   TWARPBC
                 0      DAYS      time  JAN 1 ,81
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 1salinity .3070E+02 .3070E+02
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 2Wint Phy .1750E+00 .1750E+00
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 3Summ Phy .5250E-01 .5250E-01
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 4 RPOP    .1000E-05 .1000E-05
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 5 LPOP    .1000E-05 .1000E-05
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 6 RDOP    .1000E-02 .1000E-02
C     NOBC
         2                          no. of boundary condition segments

C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 7 LDOP    .4000E-02 .4000E-02
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 8Tot PO4  .3844E-01 .3844E-01
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
 9 RPON    .1000E-05 .1000E-05
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
10 LPON    .1000E-05 .1000E-05
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
11 RDON    .1000E-02 .1000E-02
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
12 LDON    .8000E-02 .8000E-02
C     NOBC
         2                          no. of boundary condition segments
C   SCALBC
       1.0                         scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
13 Tot NH4 .7062E-01 .7062E-01
```

TABLE 5. EXAMPLE OF TIME-VARIABLE SIGMA-LEVEL BOUNDARY CONDITIONS - BCFILNA (Cont.)

```
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
14 NO23    .1050E+00 .1050E+00
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
15 BioG Si .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
16 TOT SI  .2413E+00 .2413E+00
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
17 RPOC    .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
18 LPOC    .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
19 RDOC    .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
20 LDOC    .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor

C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
21 REDOC   .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
22 EXDOC   .1000E-05 .1000E-05
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
23 AQ SOD  .0000E+00 .0000E+00
C     NOBC
           2                            no. of boundary condition segments
C   SCALBC
         1.0                           scale factor
C         LOCATIONS OF BOUNDARY SEGMENTS
 bc segs     2  1  1   2  1  2
24 DO      .1141E+02 .1141E+02
                31      time  FEB 1   81
 1salinity .3000E+02 .3000E+02
 2wint phy .2350E+00 .2350E+00
 3summ phy .4050E-01 .4050E-01
 4rpop     .1000E-05 .1000E-05
 5lpop     .1000E-05 .1000E-05
 6rdop     .1000E-02 .1000E-02
 7ldop     .4000E-02 .4000E-02
 8po4 tot  .3581E-01 .3581E-01
 9rpon     .1000E-05 .1000E-05
10 lpon    .1000E-05 .1000E-05
11 rdon    .1000E-02 .1000E-02
12 ldon    .8000E-02 .8000E-02
13 nh3 tot .7545E-01 .7545E-01
14 no23    .1060E+00 .1060E+00
15 bio si  .1000E-05 .1000E-05
16 tot si  .2919E+00 .2919E+00
17 rpoc    .1000E-05 .1000E-05
```

TABLE 5. EXAMPLE OF TIME-VARIABLE SIGMA-LEVEL BOUNDARY CONDITIONS - BCFILNA (Cont.)

```
18 lpoc     .1000E-05 .1000E-05
19 rdoc     .1000E-05 .1000E-05
20 ldoc     .1000E-05 .1000E-05
21 redoc    .1000E-05 .1000E-05
22 exdoc    .1000E-05 .1000E-05
23 aq sod   .0000E+00 .0000E+00
24 do       .1284E+02 .1284E+02
                 59      time  MAR 1      81
 1salinity .2940E+02 .2940E+02
 2wint phy .2300E+00 .2300E+00
 3summ phy .7350E-01 .7350E-01
 4rpop     .1000E-05 .1000E-05
 5lpop     .1000E-05 .1000E-05
 6rdop     .1000E-02 .1000E-02
 7ldop     .4000E-02 .4000E-02
 8po4 tot  .2241E-01 .2241E-01
 9rpon     .1000E-05 .1000E-05
10 lpon    .1000E-05 .1000E-05
11 rdon    .1000E-02 .1000E-02
12 ldon    .8000E-02 .8000E-02
13 nh3 tot .7067E-01 .7067E-01
14 no23    .3150E-01 .3150E-01
15 bio si  .1000E-05 .1000E-05
16 tot si  .1497E+00 .1497E+00
17 rpoc    .1000E-05 .1000E-05
18 lpoc    .1000E-05 .1000E-05
19 rdoc    .1000E-05 .1000E-05
20 ldoc    .1000E-05 .1000E-05
21 redoc   .1000E-05 .1000E-05
22 exdoc   .1000E-05 .1000E-05
23 aq sod  .0000E+00 .0000E+00
24 do      .1173E+02 .1173E+02
                 90     time  APR 1    81
 1salinity .2780E+02 .2780E+02
 2wint phy .1300E+00 .1300E+00
 3summ phy .6900E-01 .6900E-01
          /////////
   This portion of input file,
   covering the period from April
   through Oct is not being shown
          /////////
21 redoc   .1000E-05 .1000E-05
22 exdoc   .1000E-05 .1000E-05
23 aq sod  .0000E+00 .0000E+00
24 do      .7260E+01 .7260E+01
                304      time  NOV 1     81
 1salinity .3050E+02 .3050E+02
 2wint phy .7000E-01 .7000E-01
 3summ phy .2100E-01 .2100E-01
 4rpop     .1000E-05 .1000E-05
 5lpop     .1000E-05 .1000E-05
 6rdop     .1000E-02 .1000E-02
 7ldop     .4000E-02 .4000E-02
 8po4 tot  .5298E-01 .5298E-01
 9rpon     .1000E-05 .1000E-05
10 lpon    .1000E-05 .1000E-05
11 rdon    .1000E-02 .1000E-02
12 ldon    .8000E-02 .8000E-02
13 nh3 tot .9555E-01 .9555E-01
14 no23    .9150E-01 .9150E-01
15 bio si  .1000E-05 .1000E-05
16 tot si  .3718E+00 .3718E+00
17 rpoc    .1000E-05 .1000E-05
18 lpoc    .1000E-05 .1000E-05
19 rdoc    .1000E-05 .1000E-05
20 ldoc    .1000E-05 .1000E-05
21 redoc   .1000E-05 .1000E-05
22 exdoc   .1000E-05 .1000E-05
23 aq sod  .0000E+00 .0000E+00
24 do      .8015E+01 .8015E+01
                335      time  DEC 1     81
 1salinity .3060E+02 .3060E+02
 2wint phy .2300E+00 .2300E+00
 3summ phy .6900E-01 .6900E-01
 4rpop     .1000E-05 .1000E-05
 5lpop     .1000E-05 .1000E-05
 6rdop     .1000E-02 .1000E-02
 7ldop     .4000E-02 .4000E-02
 8po4 tot  .3999E-01 .3999E-01
 9rpon     .1000E-05 .1000E-05
10 lpon    .1000E-05 .1000E-05
11 rdon    .1000E-02 .1000E-02
12 ldon    .8000E-02 .8000E-02
13 nh3 tot .7923E-01 .7923E-01
14 no23    .1010E+00 .1010E+00
15 bio si  .1000E-05 .1000E-05
16 tot si  .2403E+00 .2403E+00
17 rpoc    .1000E-05 .1000E-05
18 lpoc    .1000E-05 .1000E-05
19 rdoc    .1000E-05 .1000E-05
20 ldoc    .1000E-05 .1000E-05
21 redoc   .1000E-05 .1000E-05
22 exdoc   .1000E-05 .1000E-05
23 aq sod  .0000E+00 .0000E+00
24 do      .9500E+01 .9500E+01
               366.0000      time JAN 1, 82 — end of simulation
```

TABLE 6. EXAMPLE OF TIME-INVARIANT STANDARD LEVEL BOUNDARY CONDITION INPUT - BCFILNA

```
C   IBCOPT   IBCLOPT
         4         0
C     NOBC
        14
C   SCALBC  - scale factor
         1.
C    NLVLS  - No of Std Lvl Depths
         4
C  Standard Level Depths
  SLDPTHS       0.00     20.00     60.00    110.00
C  BC Locations/# of Stardard Level Data to read (IX,IY,NSTLVLS)
  Salinity  19  6  4  19  7  4  19  8  4  19  9  4  19 10  4  19 11  4  19 12  4
            19 13  4  19 14  4  19 15  4  19 16  4  19 17  4  19 18  4  19 19  4
C Salinity boundary condition data for each standard level
   19, 6  0.3240E+020.3240E+020.3250E+020.3250E+02
   19, 7  0.3240E+020.3240E+020.3250E+020.3250E+02
   19, 8  0.3240E+020.3240E+020.3250E+020.3250E+02
   19, 9  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,10  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,11  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,12  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,13  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,14  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,15  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,16  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,17  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,18  0.3240E+020.3240E+020.3250E+020.3250E+02
   19,19  0.3240E+020.3240E+020.3250E+020.3250E+02
C     NOBC
        14
C   SCALBC  - scale factor
         1.
C    NLVLS  - No of Std Lvl Depths
         4
C  Standard Level Depths
  SLDPTHS       0.00     20.00     60.00    110.00
C  BC Locations/# of Stardard Level Data to read (IX,IY,NSTLVLS)
  Phyto1    19  6  4  19  7  4  19  8  4  19  9  4  19 10  4  19 11  4  19 12  4
            19 13  4  19 14  4  19 15  4  19 16  4  19 17  4  19 18  4  19 19  4
C Phytoplankton - Algal Group 1 boundary condition data for each standard level
   PHYT1  0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
          0.2000E-010.1500E-010.1000E-010.5000E-02
C     NOBC
        14
C   SCALBC  - scale factor
         1.
C    NLVLS  - No of Std Lvl Depths
         4
C  Standard Level Depths
  SLDPTHS       0.00     20.00     60.00    110.00
C  BC Locations/# of Stardard Level Data to read (IX,IY,NSTLVLS)
  Phyto2    19  6  4  19  7  4  19  8  4  19  9  4  19 10  4  19 11  4  19 12  4
            19 13  4  19 14  4  19 15  4  19 16  4  19 17  4  19 18  4  19 19  4
C Phytoplankton - Algal Group 2 boundary condition data for each standard level
  PHYT2   0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
          0.5000E-020.5000E-020.2000E-020.2000E-02
            //////////
            rest of boundary input not displayed

            //////////
```

GROUP H: POINT SOURCE LOADS (PSFILNA)

Inputs required for this group include:

1. point source loads input option
2. index table of point source loads
3. number of point source loads
4. scale factor for point source loads
5. actual point source loads

H1. Point Source Loads Input Option

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
IPSOPT	IPSPWLOPT

FORMAT (2I10)

IPSOPT = input option
= 1, all point source loads are constant in time
= 2, time-variable point source loads will be used

IPSPWLOPT = option to select step-function or piecewise linear interpolation of time-variable point source loadings.
= 0, step-function interpolation will be used
= 1, piecewise linear interpolation will be used

The remaining point source loads inputs are dependent upon the IPSOPT input option chosen. Data inputs for option 1 (constant loads) will be presented first, followed by data inputs associated with option 2 (time-variable).

H2. Index Table of Point Source Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

5	10	15	65
IPS(1,I,ISYS)	IPS(2,I,ISY)	IPS(3,I,ISYS)	LOCATION

FORMAT (3I5,A50)

IPS(1,I,ISYS) = load identifier (should be numbered consecutively from 1 through the number of point source loads included in the model
= -99 to signal end of input
IPS(2,I,ISYS) = the x-cell number of the point source load
IPS(3,I,ISYS) = the y-cell number of the point source load.
LOCATION = a 50-character alpha-numeric description of the point source load locations, ex. Blue Plains WWTP

16	22		70
ZFRACPS(1,I)	ZFRACPS(2,I)	. . .	ZFRACPS(NZ,I)

FORMAT (10X,10F6.3)

ZFRACPS(1,I) : ZFRACPS(NZ,I) = fraction of point source load discharged to layer 1,2, . . ., through NZ (note: fractions should sum up to 1.0)
If a user wished to distribute a load equally throughout the water column and if NZ=10, then ZFRACPS(1,I) through ZFRACPS(10,I) would each be set to 0.1. If a user wished to put a load in the bottom two cells only (and again if NZ=10), then ZFRACPS(1,I) through ZFRACPS(8,I) = 0.0, and ZFRACPS(9,I) = ZFRACPS(10,I) = 0.5

Constant or Time-Invariant Loads (IPSOPT = 1)

Data associated with Data Types H3, H4 and H5 will be read NOSYS times; once for each system in the model.

H3. Number of Point Source Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOPS(ISYS)

FORMAT(I10)

NOPS(ISYS) = the number of point source loads for system ISYS

(Note: If there are no point source loads to be specified for a system (NOPS = 0), then no input is required for H4 or H5; just continue with next H3.

H4. Point Source Load Scale Factor

```
                80
          Comment
      FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
                10
      SCALPS(ISYS)
      FORMAT(F10.0)
```

SCALPS(ISYS) = scale factor system ISYS

Normally SCALPS(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in point source inputs, SCALPS(ISYS) would then be set equal to 0.75.

H5. Point Source Loading Segments and Point Source Loads

```
                80
          Comment
      FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10          15                    70                  75
BPS(1,ISYS)   IPS(1,ISYS) . . .  BPS(NOPS,ISYS) IPS(NOPS,ISYS)
FORMAT(5(F10.0,I5)
```

BPS(I,ISYS) = point source load (kg/day)
IPS(I,ISYS) = index number of the point source load

Time-Variable Conditions (IPSOPT = 2)

H3. Time of Point Source Loading Specifications

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30
NXPSTSECS	TWARPPS

FORMAT (10X, I10,6X,A4)

NXPSTSECS = time in seconds (or units specified by TWARPPS
TWARPPS = units to be used for NXPSTSECS
= SECS or secs,
= MINS or mins,
= HRS or hrs,
= DAYS or days.

Data associated with Data Types H4 through H7 will be read NOSYS times; once for each system in the model.

H4. Number of Point Source Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOPS(ISYS)

FORMAT(I10)

NOPS(ISYS) = the number of point source loads for system ISYS

(Note: if NOPS equal zero, then skip H5, H6 and H7 and continue with next H4 input.)

H5. Point Source Loads Scale Factor

```
                80
        Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
                10
SCALPS(ISYS)
FORMAT(F10.0)
```

SCALPS(ISYS) = scale factor for system ISYS

H6. Point Source Loading Segments

```
          20          30          40                        80
IPS(1,ISYS)  IPS(2,ISYS)  IPS(3,ISYS)  - - -  IPS(NOPS,ISYS)
FORMAT(10X,7I10)
```

IPS(I,ISYS) = index number of the point source load

H7. Point Source Loads

```
          20          30                          80
BPS(1,ISYS)  BPS(2,ISYS)  - - -  BPS(NOPS(ISYS),ISYS)
FORMAT(10X,7F10.0)
```

BPS(I,ISYS) = point source loads (kg/day)

After input types H4 through H7 are repeated for each system, then the time of the next set of point source loads, NXPST, will be required; followed by the next set of point source loads (input type H7); it is not necessary to repeat input types H4, H5 and H6. If NOPS (ISYS) = 0 for system ISYS then no input type H7 is required either.

Table 7 presents an example input file for constant loading point source inputs. The user is referred back to Table 6 under GROUP G for an example of what a time-variable point source input file would look like.

TABLE 7. EXAMPLE OF TIME-INVARIANT OR CONSTANT POINT SOURCE INPUT - PSFILNA

```
C   IPSOPT
         1
C  NO    IX    IY Location / Vertical Distribution Fractions   (Index of Point Source Loads)
    1     5    16 Blue Plains WWTP
Fractions 0.25 0.25 0.25 0.25   0.   0.   0.   0.   0.   0.
    2    16     4 Deer Island WWTP
          0.25 0.25 0.25 0.25   0.   0.   0.   0.   0.   0.
    3    16     5 Nut Island WWTP
            0.5  0.5   0.   0.   0.   0.   0.   0.   0.   0.
    4    11    28 Tallman Island
           0.1  0.1  0.1  0.1  0.1  0.1 0 .1  0.1  0.1  0.1
    5     3    17 Rye Brook WWTP
            0.   0.   0.   0.   0.   0.   0.   0.  0.5  0.5
  -99            End of Point Source Loading Table Index
C  NOPS(1) - no point source loads for system 1
         0
C  NOPS(2) - number of loads for system 2
         5
C SCALPS(2) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
      250.   1       78.   2       6.3   4       25.   4       43.   5
C  NOPS(3) - number of loads for system 3
         5
C SCALPS(3) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
      240.   1       75.   2       6.0   4       22.   4       40.   5
C  NOPS(4) - number of loads for system 4
         5
C SCALPS(4) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
       24.   1       10.   2       0.7   4        2.   4        4.   5
C  NOPS(5) - number of loads for system 5
         4
C SCALPS(5) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
       24.   1       10.   2        2.   4        4.   5
C  NOPS(6) - number of loads for system 6
         5
C SCALPS(6) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
      2200.   1    1010.   2      250.   4      825.   4      460.   5
C  NOPS(7) - number of loads for system 7
         5
C SCALPS(7) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
      224.   1      110.   2      10.7   4       92.   4       74.   5
C  NOPS(8) - number of loads for system 8
         5
C SCALPS(8) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
      114.   1      310.   2       17.   4       52.   4       66.   5
C  NOPS(9) - number of loads for system 9
         5
C SCALPS(9) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
       44.   1       20.   2        8.   4       33.   4       24.   5
C NOPS(10) - number of loads for system 10
         5
C SCALPS(10) - scale factor
       1.0
C     Load IPS      Load IPS      Load IPS      Load IPS      Load IPS
      774.   1      510.   2       16.   4       89.   4       27.   5
```

GROUP I: NONPOINT SOURCE LOADS (NPSFILNA)

Inputs required for this group include:

1. nonpoint source loads input option
2. index table of nonpoint source loads
3. number of nonpoint source loads
4. scale factor for nonpoint source loads
5. actual nonpoint source loads

I1. Nonpoint Source Loads Input Option

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
INPSOPT	INPSPWLOPT

FORMAT (2I10)

INPSOPT = input option
= 1, all nonpoint source loads are constant in time
= 2, time-variable nonpoint source loads will be used

INPSPWLOPT = option to select step-function or piecewise linear interpolation of time variable nonpoint source loadings
= 0, step function interpolation will be used,
= 1, piecewise linear interpolation will be used

The remaining nonpoint source loading inputs are dependent upon the INPSOPT input option chosen. Data inputs for option 1 (constant loads) will be presented first, followed by data inputs associated with option 2 (time-variable).

I2. Index Table of Nonpoint Source Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

5	10	15	65
INPS(1,I,ISYS)	INPS(2,I,ISY)	INPS(3,I,ISYS)	LOCATION

FORMAT (3I5,A50)

INPS(1,I,ISYS) = load identifier (should be numbered consecutively from 1 through the number of nonpoint source loads included in the model
= -99 to signal end of input
INPS(2,I,ISYS) = the x-cell number of the nonpoint source load
INPS(3,I,ISYS) = the y-cell number of the nonpoint source load.
LOCATION = a 50-character alpha-numeric description of the nonpoint source load locations, ex. 57th Street CSO

16	22	70
ZFRACNPS(1,I)	ZFRACNPS(2,I) . . .	ZFRACNPS(NZ,I)

FORMAT (10X,10F6.3)

ZFRACNPS(1,I) = fraction of point source load discharged to layer 1,2, . . ., through NZ (note: fractions should sum up to 1.0)
:
ZFRACPS(NZ,I) If a user wished to distribute a load equally throughout the water column and if NZ=10, then ZFRACNPS(1,I) through ZFRACNPS(10,I) would each be set to 0.1. If a user wished to put a load in the bottom two cells only (and again if NZ=10), then ZFRACNPS(1,I) through ZFRACNPS(8,I) = 0.0, and ZFRACNPS(9,I) = ZFRACNPS(10,I) = 0.5

Constant or Time-Invariant Loads (INPSOPT = 1)

Data associated with Data Types I3, I4 and I5 will be read NOSYS times; once for each system in the model.

I3. Number of Nonpoint Source Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NONPS(ISYS)
FORMAT(I10)

NONPS(ISYS) = the number of nonpoint source loads for system ISYS

(Note: If there are no non-point source loads to be specified for a system (NONPS = 0), then no input is required for I4 or I5; just continue with next I3.

I4. Nonpoint Source Load Scale Factor

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALNPS(ISYS)
FORMAT(F10.0)

SCALNPS(ISYS) = scale factor for system ISYS

Normally SCALNPS(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in nonpoint source inputs, SCALNPS(ISYS) would then be set equal to 0.75.

I5. Nonpoint Source Loading Segments and Nonpoint Source Loads

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 15 70 75
BNPS(1,ISYS) INPS(1,ISYS) - - - BNPS(NONPS,ISYS) INPS(NONPS,ISYS)
FORMAT(5(F10.0,I5)

BNPS(I,ISYS) = nonpoint source load (kg/day)
INPS(I,ISYS) = index number of the nonpoint source load

Time-Variable Conditions (INPSOPT = 2)

I3. Time of Nonpoint Source Loading Specifications

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30
NXNPSTSECS	TWARPNPS

FORMAT (10X, I10,6X,A4)

NXNPSTSECS = time in seconds (or units specified by TWARPNPS)
TWARPNPS = units to be used for NXNPSTSECS
= SECS or secs,
= MINS or mins,
= HRS or hrs,
= DAYS or days.

Data associated with Data Types I4 through I7 will be read NOSYS times; once for each system in the model.

I4. Number of Nonpoint Source Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NONPS(ISYS)

FORMAT(I10)

NONPS(ISYS) = the number of nonpoint source loads for system ISYS

(Note: if NONPS equal zero, then skip I5, I6 and I7 and continue with next I4 input.)

I5. Nonpoint Source Loads Scale Factor

```
                80
          Comment
   FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
                10
SCALNPS(ISYS)
FORMAT(F10.0)
```

SCALNPS(ISYS) = scale factor for system ISYS

I6. Nonpoint Source Loading Segments

```
          20            30            40                        80
INPS(1,ISYS)  INPS(2,ISYS)  INPS(3,ISYS) - - -  INPS(NONPS,ISYS
FORMAT(10X,7I10)
```

INPS(I,ISYS) = index number of the nonpoint source load grid element

I6. Nonpoint Source Loads

```
          20            30                        80
BNPS(1,ISYS)  BNPS(2,ISYS)  - - -  BNPS(NONPS,ISYS)
FORMAT(10X,7F10.0)
```

BNPS(I,ISYS) = nonpoint source loads (kg/day)

After input types I4 through I7 are repeated for each system, then the time of the next set of nonpoint source loads, NXNPST, will be required; followed by the next set of nonpoint source loads (input type I7); it is not necessary to repeat input types I4, I5 and I6. If NONPS (ISYS) = 0 for system ISYS then no input type I7 is required either.

The user is referred back to Tables 6 and 7 for examples of what time-variable and constant input files would look like.

GROUP J: FALL-LINE LOADS (FLFILNA)

Inputs required for this group include:

1. fall-line loads input option
2. index table of fall-line loads
3. number of fall-line loads
4. scale factor for fall-line loads
5. actual fall-line loads

J1. Fall-line Loads Input Option

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	
IFLOPT	IFLPWLOPT

FORMAT(2I10)

IFLOPT = input option
= 1, all fall-line loads are constant in time
= 2, time-variable fall-line loads will be used

IFLPWLOPT = option to select step-function or piecewise linear interpolation of time-variable fall-line source loadings.
= 0, step function interpolation will be used,
= 1, piecewise linear interpolation will be used.

The remaining fall-line loading inputs are dependent upon the IFLOPT input option chosen. Data inputs for option 1 (constant loads) will be presented first, followed by data inputs associated with option 2 (time-variable).

J2. Index Table of Fall-Line Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

5	10	15	65
IFL(1,I,ISYS)	IFL(2,I,ISY)	IFL(3,I,ISYS)	LOCATION

FORMAT (3I5,A50)

IFL(1,I,ISYS) = load identifier (should be numbered consecutively from 1 through the number of fall-line loads included in the model = -99 to signal end of input
IFL(2,I,ISYS) = the x-cell number of the fall-line load
IFL(3,I,ISYS) = the y-cell number of the fall-line load.
LOCATION = a 50-character alpha-numeric description of the fall-line load locations, ex. Branch Brook Inflow

16	22	70
ZFRACFL(1,I)	ZFRACFL(2,I) . . .	ZFRACFL(NZ,I)

FORMAT (10X,10F6.3)

ZFRACFL(1,I)
:
ZFRACFL(NZ,I) = fraction of fall-line load discharged to layer 1,2, . . . , through NZ (note: fractions should sum up to 1.0) If a user wished to distribute a load equally throughout the water column and if NZ=10, then ZFRACFL(1,I) through ZFRACFL(10,I) would each be set to 0.1. If a user wished to put a load in the bottom two cells only (and again if NZ=10), then ZFRACFL(1,I) through ZFRACFL(8,I) = 0.0, and ZFRACFL(9,I) = ZFRACFL(10,I) = 0.5

Constant or Time-Invariant Loads (IFLOPT = 1)

Data associated with Data Types J3, J4 and J5 will be read NOSYS times; once for each system in the model.

J3. Number of Fall-line Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

5
NOFL(ISYS)

FORMAT(10)

NOFL(ISYS) = the number of fall-line loads for system ISYS

(Note: If there are no fall-line loads to be specified for a system (NOFL = 0), then no input is required for J4 or J5; just continue with next J3.)

J4. Fall-line Load Scale Factor

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALFL(ISYS)

FORMAT(F10.0)

SCALFL(ISYS) = scale factor for system ISYS

Normally SCALFL(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in fall-line inputs, SCALFL(ISYS) would then be set equal to 0.75.

J5. Fall-line Loading Segments and Fall-line Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	15	70	75
BFL(1,ISYS)	IFL(1,ISYS)	BFL(NOFL,ISYS)	IFL(NOFL,ISYS)

FORMAT(5(F10.0,I5))

BFL(I,ISYS) = fall-line load (kg/day)
IFL(I,ISYS) = index number of the fall-line load

Time-Variable Conditions (IFLOPT = 2)

J3. Time of Fall-line Loading Specifications

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30
NXFLTSECS	TWARPFL
FORMAT (10X, I10,6X,A4)	

NXFLTSECS = time in seconds (or units specified by TWARPFL)
TWARPFL = units to be used for NXFLTSECS
= SECS or secs,
= MINS or mins,
= HRS or hrs,
= DAYS or days.

Data associated with Data Types J4 through J7 will be read NOSYS times; once for each system in the model.

J4. Number of Fall-line Loads

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

5
NOFL(ISYS)
FORMAT(10)

NOFL(ISYS) = the number of fall-line loads for system ISYS

(Note: if NOFL equal zero, then skip J5, J6 and J7 and continue with next J4 input.)

J5. Fall-line Loads Scale Factor

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10
SCALFL(ISYS)
FORMAT(F10.0)
```

SCALFL(ISYS) = scale factor system ISYS

J6. Fall-line Loading Segments

```
          20          30          40                    80
IFL(1,ISYS)  IFL(2,ISYS)  IFL(3,ISYS)  - - -  IFL(NOFL,ISYS)
FORMAT(10X,7I10)
```

IFL(1,I,ISYS) = index number of the fall-line load

J7. Fall-line Loads

```
          20          30                    80
BFL(1,ISYS)  BFL(2,ISYS)  - - -  BFL(NOFL(ISYS),ISYS)
FORMAT(10X,7F10.0)
```

BFL(I,ISYS) = fall-line loads (kg/day)

After input types J4 through J7 are repeated for each system, then the time of the next set of fall-line loads, NXFLT, will be required; followed by the next set of fall-line loads (input type J7); it is not necessary to repeat input types J4, J5 and J6. If NOFL (ISYS) = 0 for system ISYS then no input type J7 is required either.

The user is referred back to Tables 6 and 7 for examples of what time-variable and constant input files would look like.

GROUP K: ATMOSPHERIC LOADS (ATMFILNA)

Inputs required for this group include:

1. atmospheric loads input option
2. number of atmospheric loads
3. scale factor for atmospheric loads
4. actual atmospheric loads

K1. Atmospheric Loads Input Option

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
IATMOPT	IATMPWLOPT

FORMAT (2I10)

IATMOPT = input option
= 1, all atmospheric loads are constant in time
= 2, time-variable atmospheric loads will be used

IATMPWLOPT = option to select step-function or piecewise linear interpolation of time-variable atmospheric loadings.
= 0, step-function interpolation will be used,
= 1, piecewise linear interpolation will be used.

The remaining atmospheric loading inputs are dependent upon the IATMOPT input option chosen. Data inputs for option 1 (constant loads) will be presented first, followed by data inputs associated with option 2 (time-variable).

Constant or Time-Invariant Loads (IATMOPT = 1)

Data associated with Data Types K2, K3 and K4 will be read NOSYS times; once for each system in the model.

K2. Number of Atmospheric Loads

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

5
NOATM(ISYS)
FORMAT(I10)

NOATM(ISYS) = the number of atmospheric loads for system ISYS
= 0, no atmospheric loading for system ISYS
= 1, spatially-constant atmospheric loadings to water surface
= 2, spatially-variable atmospheric loadings to water surface

(Note: If there are no atmospheric inputs to be specified for a system (NOATM = 0), then no input is required for K3 or K4; just continue with next K2.

K3. Atmospheric Load Scale Factor

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALATM(ISYS)
FORMAT(F10.0)

SCALATM(ISYS) = scale factor for system ISYS

Normally SCALATM(ISYS) would be set equal to 1.0, however, if the user wished to perform a sensitivity run to a 25 percent reduction in atmospheric inputs, SCALATM(ISYS) would then be set equal to 0.75.

Spatially Constant Atmospheric Loads (NOATM (ISYS=1)

K4. Atmospheric Loading Rate

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

20
BATM(ISYS)

FORMAT(10X,F10.0)

BATM(ISYS) = atmospheric loading rate (kg/m^2-day)

RCA will take the areal atmospheric loading rate for system ISYS and apply this loading rate to each water segment in the model by multiplying the wetted surface area of the segment by the areal loading rate to compute the total kg/day loading to the water segment.

Spatially-Variable Atmospheric Loads (NOATM = 2)

K4. Atmospheric Loading Rates

20	30	80
BATM(1,1,ISYS)	BATM(2,1,ISYS) - - -	BATM(NX,1,ISYS)
.	.	.
.	.	.
.	.	.

20	30	80
BATM(1,NY,ISYS)	BATM(2,NY,ISYS) - - -	BATM(NX,NY,ISYS)

FORMAT(10X,7F10.0)

BATM(IX,IY,ISYS) = atmospheric loading rate (kg/m^2-day) for segment or grid cell (IX,IY) for system ISYS

Time-Variable Conditions (IATMOPT = 2)

K2. Time of Atmospheric Loading Specifications

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30
NXATMTSECS	TWARPATM

FORMAT (10X, F10.0 6X,A4)

NXATMTSECS = time in seconds (or units specified by TWARPATM
TWARPATM = units to be used for NXATMTSECS
= SECS or secs,

= MINS or mins,
= HRS or hrs,
= DAYS or days.

Data associated with Data Types K3, K4 and K5 will be read NOSYS times; once for each system in the model.

K3. Number of Atmospheric Loads

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

5
NOATM(ISYS)
FORMAT(10)

NOATM(ISYS) = the number of atmospheric loads for system ISYS
= 0, for no atmospheric loading for system ISYS
= 1, spatially-constant atmospheric loading to water surface
= 2, spatially-variable atmospheric loadings to water surface

(Note: if NOATM equal zero, then skip K4 and K5 and continue with next K3 input.)

K4. Atmospheric Loads Scale Factor

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALATM(ISYS)
FORMAT(F10.0)

SCALATM(ISYS) = scale factor for system ISYS

Spatially-Constant Atmospheric Loading (NOATM(ISYS) = 1)

K5. Atmospheric Loading Rate

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20
BATM(ISYS)

FORMAT(10X,F10.0)

BATM(ISYS) = atmospheric loading rate (kg/m2-day)

Spatially-Variable Atmospheric Loads (NOATM(ISYS) = 2)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

K5. Atmospheric Loading Rates

20	30	80
BATM(1,1,ISYS)	BATM(2,1,ISYS)	- - - BATM(NX,1,ISYS)
.	.	.
.	.	.
.	.	.

20	30	80
BATM(1,NY,ISYS)	BATM(2,NY,ISYS)	- - - BATM(NX,NY,ISYS)

FORMAT(10X,7F10.0)

BATM(IX,IY,ISYS) = atmospheric loading rate for segment or grid cell (IX,IY) for system ISYS

After input types K3 through K5 are repeated for each system, then the time of the next set of atmospheric loads, NXATMT, will be required; followed by the next set of atmospheric loads (input type K5); it is not necessary to repeat input types K3 and K4. If NOATM (ISYS) = 0 for a system then no input type K5 is required either.

RCA will take the areal atmospheric loading rate for system ISYS and apply it to each water segment in the model by and multiplying the wetted surface area of the receiving water segment by the loading rate to compute the total kg/day loading to the segment.

Tables 8 and 9 provide example input files for constant and time-variable inputs.

TABLE 8. EXAMPLE OF TIME-INVARIANT OR CONSTANT POINT SOURCE INPUT - PSFILNA

```
C  IATMOPT
         1
C  NOATM(1)   no salinity loads
         0
C  NOATM(2)   no phytoplankton loads
         0
C  NOATM(3)   no phytoplankton loads
         0
C  NOATM(4)   no RPOP loads
         0
C  NOATM(5)   no LPOP loads
         0
C  NOATM(6)   no RDOP loads
         0
C  NOATM(7)   no LDOP loads
         0
C  NOATM(8)   DPO4 load
         1
C  SCALATM
       1.0
C   PO4 load (kg/m2-day) == 0.011 mg P/L * 47 inches rainfall/yr
        0.3600E-07
C  NOATM(9)   no RPON loads
         0
C NOATM(10)   no LPON loads
         0
C NOATM(11)   no RDON loads
         0
C NOATM(12)   no LDON loads
         0
C NOATM(13)   NH4 loads
         1
C  SCALATM
       1.0
C  NH4 load (kg/m2-day) == 0.15 mg N/L * 47 in/yr = 0.15 g N/m3 * 1.194 m/yr * yr/365 day *
kg/1000 g
        0.4907E-06
C NOATM(14)   NO3 loads
         1
C  SCALATM
       1.0
C  NO3 load (kg/m2-day) == 0.43 mg N/L * 47 in/yr
         1.4066E-06
C NOATM(15)   no BSi loads
         0
C NOATM(16)   no DSI loads
  loads        0
C NOATM(17)   no RPOC loads
         0
C NOATM(18)   no LPOC loads
         0
C NOATM(19)   no RDOC loads
         0
C NOATM(20)   no LDOC loads
         0
C NOATM(21)   no ReDOC loads
         0
C NOATM(22)   no ExDOC loads
         0
C NOATM(23)   no O2eq loads
         0
C NOATM(24)   no DO loads
          0
```

TABLE 9. EXAMPLE OF TIME-VARIABLE ATMOSPHERIC INPUT - ATMFILNA TABLE

```
C  IATMOPT IATMPWLOPT
         2         0
          NXATMTSECS  TWARPATM
                   0      DAYS
C  NOATM(1)   no salinity load
           0
C  NOATM(2)   no phytoplankton load
           0
C  NOATM(3)   no phytoplankton load
           0
C  NOATM(4)   no RPOP load
           0
C  NOATM(5)   no LPOP load
           0
C  NOATM(6)   no RDOP load
           0
C  NOATM(7)   no LDOP load
           0
C  NOATM(8)   DPO4 load
           1
C  SCALATM        assumes 0.011 mg P/L in rainfall and the value specified by BATM is
 2.794E-06        monthly-averaged rainfall in inches/day
C   PO4 load      following value is total rainfall in January (3.1 inches) / 31 days
            0.100
C  NOATM(9)   no RPON load
           0
C NOATM(10)   no LPON load
           0
C NOATM(11)   no RDON load
           0
C NOATM(12)   no LDON load
           0
C NOATM(13)   NH4 load
           1
C  SCALATM        assumes 0.15 mg N/L in rainfall and the value specified by BATM is
 3.810E-05        monthly-averaged rainfall in inches/day
C  NH4 load       following value is total rainfall in January (3.1 inches) / 31 days
            0.100
C NOATM(14)   NO3 load
           1
C  SCALATM        assumes 0.43 mg N/L in rainfall and the value specified by BATM is
 1.092E-04        monthly-averaged rainfall in inches/day
C  NO3 load       following value is total rainfall in January (3.1 inches) / 31 days
            0.100
C NOATM(15)   no BSi load
           0
C NOATM(16)   no DSI load
           0
C NOATM(17)   no RPOC load
           0
C NOATM(18)   no LPOC load
           0
C NOATM(19)   no RDOC load
           0
C NOATM(20)   no LDOC load
           0
C NOATM(21)   no ReDOC load
           0
C NOATM(22)   no ExDOC load
           0
C NOATM(23)   no O2eq load
           0
C NOATM(24)   no DO load
           0
TIME              31
 PO4          0.07786      2.18 inches / 28 days
 NH4          0.07786      2.18 inches / 28 days
 NO3          0.07786      2.18 inches / 28 days
TIME              59
 PO4          0.10581      3.28 inches / 31 days
 NH4          0.10581      3.28 inches / 31 days
 NO3          0.10581      3.28 inches / 31 days
TIME              90
 PO4          0.08500      2.55 inches / 30 days
 NH4          0.08500      2.55 inches / 30 days
 NO3          0.08500      2.55 inches / 30 days
TIME             120
 PO4          0.08903      2.76 inches / 31 days
```

TABLE 9. EXAMPLE OF TIME-VARIABLE ATMOSPHERIC INPUT - ATMFILNA TABLE (Cont.)

```
 NH4          0.08903      2.76 inches / 31 days
 NO3          0.08903      2.76 inches / 31 days
TIME              151
 PO4          0.01060      3.18 inches / 30 days
 NH4          0.01060      3.18 inches / 30 days
 NO3          0.01060      3.18 inches / 30 days
TIME              181
 PO4          0.04871      1.51 inches / 31 days
 NH4          0.04871      1.51 inches / 31 days
 NO3          0.04871      1.51 inches / 31 days
TIME              212
 PO4          0.03581      1.11 inches / 31 days
 NH4          0.03581      1.11 inches / 31 days
 NO3          0.03581      1.11 inches / 31 days
TIME              243
 PO4          0.13500      4.05 inches / 30 days
 NH4          0.13500      4.05 inches / 30 days
 NO3          0.13500      4.05 inches / 30 days
TIME              273
 PO4          0.06484      2.01 inches / 31 days
 NH4          0.06484      2.01 inches / 31 days
 NO3          0.06484      2.01 inches / 31 days
TIME              304
 PO4          0.08266      2.48 inches / 30 days
 NH4          0.08266      2.48 inches / 30 days
 NO3          0.08266      2.48 inches / 30 days
TIME              334
 PO4          0.05677      1.76 inches / 31 days
 NH4          0.05677      1.76 inches / 31 days
 NO3          0.05677      1.76 inches / 31 days
TIME              366
```

GROUP L: PARAMETERS, CONSTANTS AND TIME-VARIABLE FUNCTIONS (PCFILNA)

Inputs required for this group include:

1. number of 2-D parameters
2. scale factors for 2-D parameters
3. parameter names
4. actual 2-D parameters
5. number of 3-D parameters
6. scale factors for 3-D parameters
7. parameter names
8. actual 3-D parameters
9. number of constants
10. actual constants
11. number of time-variable functions (tvfs)
12. tvf name and the number of time-breaks required to specify the tvf
13. actual tvfs
14. number of kinetic specific input file names
15. file names

L1. The Number of 2-Dimensional Parameters

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NPARM2D

FORMAT(I10)

NPARM2D = number of 2-dimensional (or depth-independent) parameters

If there are no 2-D parameters to be read, skip over the next three input types and proceed with input type L5.

L2. 2-D Scale Factors

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
      10        20                    80
PSCAL(1)  PSCAL(2)  - - -  PSCAL(NPARM2D)
FORMAT(8F10.0)
```

PSCAL(I) = scale factor for the Ith 2-D parameter set

L3. Parameter Name

```
    20
PNAME
FORMAT(A20)
```

PNAME = alphanumeric name for parameter set to be read

L4. 2-D Parameters

```
            10              20              30                    80
PARAM2D(1,1,I)  PARAM2D(2,1,I)  PARAM2D(3,1,I)  - - -  PARAM2D(NX1,2,I)
      .          .               .                     .
      .          .               .                     .
      .          .               .                     .
            10              20                  80
PARAM2D(1,NY,I)  PARAM2D(2,NY,I)  - - -  PARAM2D(NX,NY,I)
FORMAT(8F10.0)
```

PARAM2D(IX,IY,I) = value of the Ith parameter in segment or grid cell (IX,IY)

The parameters for the Ith parameter set are read a column at a time. The equivalent FORTRAN read statements would be:

```
DO I = 1,NPARM2D
 DO IY = 1,NY
  READ *, (PARAM2D(IX,IY,I), IX = 1, NX)
 ENDDO
ENDDO
```

L5. The Number of 3-Dimensional Parameters

```
                80
          Comment
   FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          5
NPARM3D
FORMAT(10)
```

NPARM3D = number of 3-dimensional (or depth-dependent) parameters

If there are no 3-D parameters to be read, skip over the next three input types and proceed with input type L9.

L6. 3-D Parameter Scale Factors

```
                80
          Comment
   FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
        10          20                        80
PSCAL(1)  PSCAL(2)  - - -  PSCAL(NPARM3D)
FORMAT(8F10.0)
```

PSCAL(I) = scale factor for the Ith 3-D parameter set

L7. Parameter Name

```
      20
PNAME
FORMAT(A20)
```

PNAME = alphanumeric name for parameter set to be read

L8. 3-D Parameters

10	20	80
PARAM3D(1,1,1,I)	PARAM3D(2,1,1,I) - - -	PARAM3D(NX,1,1,I)
.	.	.
.	.	.
.	.	.

10	80
PARAM3D(1,NY,NZ,I) - - -	PARAM3D(NX,NY,NZ,I)

FORMAT(8F10.0)

PARAM3D(IX,IY,IZ,I) = value of the Ith parameter in segment (IX,IY,IZ)

The parameters for the Ith parameter set are read by layer, by column. The equivalent FORTRAN read statement would be:

```
DO I = 1,NPARM3D
 DO IZ = 1,NZ
  DO IY = 1,NY
   READ *,(PARAM3D(IX,IY,IZ,I), IX = 1, NX)
  ENDDO
 ENDDO
ENDDO
```

Input types L7 and L8 are read for each parameter set, from 1 through NPARM3D.

L9. Number of Constants

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NCONS

FORMAT(I10)

NCONS = number of constants to be read

If no constants are to be read, set NCONS equal to 0 and continue with input type L11.

L10. Constants

```
        10          20              80
CNAME(1)   CNAME(2)  - - -  CNAME(8)
CONST(1)   CONST(2)  - - -  CONST(8)
        .          .                .
        .          .                .
        .          .                .
CNAME(NOCONS-1) CNAME(NOCONS)
CONST (NOCONS-1) CONST (NOCONS)
FORMAT(8A10/8F10.0)
```

CNAME(1) = name of the Ith constant
CONST(I) = value of the Ith constant

The specification of CNAME is optional, but by specifying alphanumeric text it facilitates editing the constants section of the input file.

L11. Number of Time-Variable Functions (TVFs)

```
              80
        Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
        10          20
NOFUNC  ITVFPLOPT
FORMAT(2I10)
```

NOFUNC = number of time-variable functions to be read
ITVFPLOPT = step function or piecewise linear interpolation option
= 0, use step function
= 1, use piece wise linear interpolation

Data associated with Data Types L12 and L13 will be read NOFUNC times; once for each time-variable function required by the model.

L12. TVF Name and the Number of TVF Time Breaks
(Note if NOFUNC = 0, no input is required for L12 and L13.)

```
              80
        Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

10	20	30
PNAME	NOBRK	TWARPTWF

FORMAT
(A10,I10,6X,A4)

PNAME = name of the time-variable function (tvf)
NOBRK = number of time breaks required to specify the tvf
TWARPTWF = units to be used for the time breaks in the tvf.
= SECS or secs,
= MINS or mins,
= HRS or hrs,
= DAYS or days.

L13. Time-Variable Function

10	20	30	40		70	80
VALT(1)	T(1)	VALT(2)	T(2)	- - -	VALT(NOBRK)	T(NOBRK)

FORMAT(8F10.0)

VALT(I) = value of the function at time T(I)
T(I) = time in seconds (or units specified by TWARPTVF).

Note: Unlike previous versions of RCA all tvfs do not have to use the same time breaks (T(I)).

L14. Number of Miscellaneous Input Files to be Used by the Kinetic Subroutine

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
NOKINFILNA

FORMAT (I10)

NOKINFILNA = number of file names to be read

L15. File Names

40
KINFILNA(I)
FORMAT(A40)

KINFILNA(I) = complete path length and file name for kinetic subroutine input file I. The number of file names and the order in which they are specified is determined by the kinetic subroutine being used.

Table 10 presents a sample parameter, constant, tvf input file for a model with 10 cells in the x-direction, 5 cells in the y-direction, and 2 vertical layers with two 2-D parameters, one 3-D parameter, 44 constants, 1 time-variable function and 2 kinetic subroutine specific input files.

TABLE 10. EXAMPLE OF A PARAMETER, CONSTANTS AND TIME-VARIABLE FUNCTION INPUT FILE - PCFILNA

```
C N2DPARAM
         2
C    Scale1    Scale2
    0.3048       1.0
C   Ke - extinction coefficient
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
     0.000     0.000
     0.000     0.787     0.787     0.850     0.880     0.925     1.250     1.150
     1.050     0.000
     0.000     0.787     0.787     0.850     0.880     0.920     1.170     1.120
     1.000     0.000
     0.000     0.787     0.787     0.840     0.870     0.900     0.980     1.100
     1.000     0.000
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
     0.000     0.000
C   Kl - mass trasnfer coefficient  (reaeration coefficient)
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0
       0.0       1.5       1.5       1.5       1.5       1.0       1.0       1.0
       1.5       0.0
       0.0       1.5       1.5       1.5       1.5       1.0       1.0       1.0
       1.5       0.0
       0.0       1.5       1.5       1.5       1.5       1.0       1.0       1.0
       1.5       0.0
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0
C N3DPARAM
         1                                       number of 3D parameters
C    SCALE
   1.0E-00
C   SS (mg/L)
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0                                             layer 1
       0.0       15.       15.       15.       14.       12.       10.       10.
       10.       0.0
       0.0       15.       15.       15.       14.       12.       10.       10.
       10.       0.0
       0.0       15.       15.       15.       14.       12.       10.       10.
       10.       0.0
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0                                             layer 2
       0.0       18.       18.       18.       16.       14.       12.       11.
       11.       0.0
       0.0       18.       18.       18.       16.       14.       12.       11.
       11.       0.0
       0.0       18.       18.       18.       16.       14.       12.       11.
       11.       0.0
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0
C    NCONS
        20                                     number of constants
     AGOPT     KAOPT     KEOPT    Unused    Unused     TOPT1   K1BETA1   K2BETA2
        0.        1.        2.                           3.50      .004      .006
       K1C       K1T       IS1      KMN1      KMP1      KMS1      K1RB      K1RG
     2.500     1.068   150.000     0.010     0.001     0.020     0.075       0.0
      K1RT     K1GZC     K1GZT     CCHL1     CPR11     CPR12     CPR13     CNR11
     1.047     0.100      1.10      30.0      40.0       0.0       0.0     5.670
     CNR12     CNR13     CSR11     CSR12     CSR13     TOPT2   K2BETA1   K2BETA2
       0.0       0.0       5.0      10.0       0.0       22.      .004      .006
       K2C       K2T       IS2      KMN2      KMP2      KMS2      K2RB      K2RG
     2.400     1.068     350.0     0.010     0.001     0.002     0.075        0.
      K2RT     K2GZC     K2GRT     CCHL2
     1.047     0.120     1.100      80.0
C    NOTVF  TVPWLOPT                        number of time functions
         1         1
C    PNAME     NOBRK  TWARPTVF
      ITOT        13      DAYS       TOTAL DAILY RADIATION
      118.        0.      168.       11.      218.       59.      318.       90.
      418.      120.      468.      151.      518.      181.      468.      212.
      418.      243.      318.      273.      218.      304.      168.      335.
      118.      365.
C NOKINFILNA
         2
sed.inp
/users/potomac/vegm.inp
```

GROUP M: INITIAL CONDITIONS

Inputs required for this group include:

1. sigma level or standard level input option
2. initial conditions

M1. Option to Read Initial Conditions Using Sigma Levels or Standard Levels

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
ICOPT

FORMAT(I0)

ICOPT = sigma-level or standard level input option
= 0, use sigma-level
= 1, use standard level

Sigma-Level Initial Conditions (ICOPT=0)

M2. Initial Conditions (or Initial Solution Estimates)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

20	30	80
CARAY(1,1,1,ISYS)	CARAY(2,1,1,ISYS) - - -	CARAY(NX,1,1,ISYS)
.	.	.	.
.	.	.	.
.	.	.	.

20	80
CARAY(1,NY,NZ,ISYS)	- - - CARAY(NX,NY,NZ,ISYS)

FORMAT(10X,7F10.0)

CARAY(IX,IY,IZ,ISYS)= initial condition for segment grid cell (IX,IY,IZ) for system ISYS

The initial conditions are read by system, by layer, by y-direction. The equivalent read statement would be:

```
DO ISYS = 1,NOSYS
 DO IZ = 1,NZ
  DO IY = 1,NY
   READ *, (CARAY(IX,IY,IZ,ISYS), IX = 1,NX)
  ENDDO
 ENDDO
ENDDO
```

Standard Level Initial Conditions (ICOPT=1)

M2. Number of Standard Levels

```
                80
        Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
    10
 NLVLS
FORMAT(I10)
```

NLVLS = number of standard levels at which initial conditions are defined

M3. Standard Level Depths

```
          10              20                    80
SLDEPTH(1)  SLDEPTH(2) . . . SLDEPTH(NLVLS)
```

SLDEPTH(1) = the depth in meters of the I^{TH} standard level

M4. Initial Conditions at Standard Levels

```
              20                30                    80
CARAYSL(1,1,1)  CARAYSL(2,1,1)    . . .    CARAYSL(NX1,1)
        .           .                          .
        .           .                          .
        .           .                          .
                    20                                  80
CARAYSL(1,NY,NLVLS)      . . .      CARAYSL(NX,NY,NLVLS)
FORMAT(10X,7F10.0)
```

CARAYSL(IX,IY,IZ) = initial condition at standard depth level IZ for segment grid cell (IX,IY)

APPENDIX A

INTEGRATED EUTROPHICATION AND SEDIMENT NUTRIENT FLUX MODELS

TABLE OF CONTENTS

1.0 KINETIC FRAMEWORK FOR THE INTEGRATED EUTROPHICATION MODEL . . . 1
1.1 INTRODUCTION . . . 1
1.1.1 Conservation of Mass . . . 1
1.1.2 Choice of State Variables . . . 3
1.2 MODEL KINETICS . . . 4
1.2.1 General Structure . . . 4
1.2.2 Phytoplankton Growth and Loss Kinetics . . . 5
1.2.2.1 Standard Algal Growth Model . . . 6
1.2.2.2 Laws-Chalup Algal Growth Model . . . 13
1.2.3 Stoichiometry and Uptake Kinetics . . . 19
1.2.3.1 Algal Stoichiometry and Uptake Kinetics - Standard Algal Growth Model . . .
1.2.3.2 Algal Stoichiometry and Uptake Kinetics - Laws-Chalup Algal Growth Model . . . 20
1.2.3.3 Nutrient Cycling . . . 22
1.2.3.4 Organic Carbon . . . 23
1.2.3.6 Nitrogen . . . 28
1.2.3.7 Silica . . . 35
1.2.3.8 Dissolved Oxygen . . . 35
1.2.4 Specification of Input Variables Associated with the Eutrophication Model . 41
1.2.4.1 Parameters, Constants, and Time Functions . . . 51

2.0 FRAMEWORK FOR THE SEDIMENT FLUX SUBMODEL . . . 60
2.1 Overview of Model Framework . . . 60
2.2 Diagenesis . . . 60
2.3 The General Sediment Model Equations . . . 62
2.3.1 Surface Mass Transfer Coefficient and Reaction Velocities . . . 63
2.3.2 Particulate Phase Mixing . . . 65
2.3.3 Benthic Stress . . . 65
2.3.4 Dissolved Phase Mixing . . . 66
2.3.5 Solids Burial . . . 67
2.3.6 Active Layer Depth . . . 67

3.0 REFERENCES . . . 89

TABLES

Table 1-1. Standard Phytoplankton Growth Equations 11
Table 1-2. Laws-chalup Phytoplankton Growth Equations 16
Table 1-3. Variable Stoichiometry Coefficients 20
Table 1-4 Variable Stoichiometry Coefficients - Laws-chalup Algal Growth Model 22
Table 1-5. Organic Carbon Reaction Equations 25
Table 1-6. Phosphorus Reaction Rates 29
Table 1-7. Nitrogen Reaction Rates 32
Table 1-8. Silica Reaction Equations 36
Table 1-9. Dissolved Oxygen and O Reaction Rates 39
Table 1-10. Kinetic Constants Used for Standard Eutrophication Algal Growth Model 42
Table 1-10. Kinetic Constants Used for Standard Eutrophication Algal Growth Model 43
Table 1-10. Kinetic Constants Used for Standard Eutrophication Algal Growth Model 44
Table 1-11. Kinetic Constants Used for Laws-chalup Eutrophication Algal Growth Model 45
Table 1-12. Remaining Kinetic Constants Used for Integrated Eutrophication Model 48
Table 1-13. 2-D Parameters 51
Table 1-14. Time-variable Functions 51
Table 1-15. Sample Eutrophication Input Dataset 52
Table 2-1. Sediment Model Coefficients 68
Table 2-2. Sample Input Deck for the Sediment Model Coefficient Set 86

FIGURES

Figure 1-1. Principal Kinetic Interactions for Nutrient Cycles and Dissolved Oxygen 54
Figure 1-2. Growth Rate as a Function of Temperature 55
Figure 1-3. Carbon-to-phosphorus Ratio (mean and standard error) of Seston in Upper Chesapeake Bay. Bars Show Number of Observations. 56
Figure 1-4. Carbon to Nitrogen Ratios as a Function of the Concentration of Dissolved Inorganic nitrogen 57
Figure 1-5. Settling Rate as a Function of Concentration and β (Beta) and C_{ref} 58
Figure 1-6. Behavior of the Ammonia Preference Structure for Various Concentrations of NH_3 and NO_2+NO_3. 59

1.0 KINETIC FRAMEWORK FOR THE INTEGRATED EUTROPHICATION MODEL

1.1 INTRODUCTION

This portion of the RCA Users Guide describes an integrated eutrophication/sediment nutrient flux modeling framework, available with the Public Domain release of RCA. In addition, the range in kinetic coefficients used in a number of eutrophication studies performed by HydroQual are provided as a reference.

1.1.1 Conservation of Mass

The modeling framework described in this document is based upon the principle of conservation of mass. The conservation of mass accounts for all of a material entering or leaving a body of water, transport of the material within the water body, and physical, chemical and biological transformations of the material. For an infinitesimal volume oriented along the axis of a three-dimensional coordinate system, a mathematical formulation of the conservation of mass may be written:

$$\frac{\partial c}{\partial t} = \underbrace{\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right)}_{\text{dispersive transport}} \underbrace{- U_x \frac{\partial c}{\partial x} - U_y \frac{\partial c}{\partial y} - U_z \frac{\partial c}{\partial z}}_{\text{advective transport}} \qquad (1\text{-}1)$$

$$\underbrace{\pm S(x,y,z,t)}_{\text{sources or sinks}} + \underbrace{W(x,y,z,t)}_{\text{external inputs}}$$

where:

c	=	concentration of the water quality variable [M/L^3],
t	=	time [T],
E	=	dispersion (mixing) coefficient due to tides and density and velocity gradients (L^2/T),
U	=	advective velocity (L/T),
S	=	sources and sinks of the water quality variable, representing kinetic interactions (M/L^3-T),
W	=	external inputs of the variable c (M/L^3-T),
x,y,z	=	longitudinal, lateral and vertical coordinates,
M,L,T	=	units of mass, length and time, respectively.

The modeling framework is made up of two components: (1) the transport due to freshwater flow in riverine systems and/or tidal, meteorological and density-driven currents in esturaine and coastal systems, and (2) the kinetic interactions between variables and the external inputs . Freshwater flow and/or density-driven currents and tidally and wind induced mixing are responsible for the movement of the water quality constituents within the waterbody.

External inputs of nutrients and oxygen-demanding material are derived from numerous sources, including: municipal and industrial discharges, combined sewer overflows (CSOs), storm sewer overflows (SSOs), natural surface runoff, and atmospheric deposition to the water surface of the waterbody.

The kinetics control the rates of interactions among the water quality constituents. Ideally, in a modeling effort, they should be independent of location per se, although they may be functions of exogenous variables, such as temperature and light, which may vary with location.

Analytical solutions are not available for partial differential equations of the form of Equation 1-1 except for the simplest cases. Instead, numerical methods are utilized to solve these mass balance equations. A specific method of solution employed in a majority of water quality modeling frameworks is known as the finite difference technique. First, the estuary is divided into finite volumes. Then a finite difference approximation of Equation 1-1 is applied to the ith finite volume or segment, resulting in an equation of the form (see Thomann and Mueller, 1987):

$$V_i \frac{dc_i}{dt} = \sum_{j=1}^{n} R_{ij}\left(c_j - c_i\right) + \sum_{k=1}^{n} Q_{ki} c_k - \sum_{m=1}^{n} Q_{im} c_i \pm S_i + W_i \qquad (1\text{-}2)$$

$i = 1, 2, \ldots n$ (where n = number of segments)

where

V_i = volume of segment i (L^3),
c_i = concentration of the water quality variable in the ith segment, (M/L^3),
R_{ij} = exchange between segment i and j resulting from dispersive mixing, (L^3/T),
Q_{ki} = net advective flow entering segment i from segment k, (L^3/T),
Q_{im} = net advective flow leaving segment i and going to segment m, (L^3/T),
S_i = sources and sinks, in segment i representing kinetic interactions, (M/T),
W_i = external inputs to segment i (M/T).

The exchange coefficients and advective flows are computed from

$$R_{ij} = \frac{E_{ij} A_{ij}}{L_{ij}} \qquad (1\text{-}3a)$$

and

$$Q_{ij} = A_{ij} U_{ij} \qquad (1\text{-}3b)$$

respectively, where E_{ij} is the dispersion coefficient, representing the overall phenomenon of mixing due to temporal variations in the tidal velocity, lateral and vertical gradients in velocity, and density differences within the water body; A_{ij} is the cross-sectional area of the ij interface; L_{ij} is the characteristic length defined as $(L_i + L_j)/2$; and U_{ij} is the net advective velocity from segment i to j. The term S_i, the sources and sinks of material in segment i, represents the kinetic interactions (physical, chemical and biological) occurring within the segment. These interactions may be functions only of the variable under consideration, for example, the first order decay of organic material. Alternately, they may involve the interactions between other variables, e.g., the first order feed-forward interaction between the oxidation of organic carbon (BOD) and dissolved oxygen, or the more complex interactions between phytoplankton biomass and nutrients, which involve non-linear feed-forward and feed-back interactions. The term W_i represents the external inputs of material into segment i, including point and nonpoint source loads, CSO loads, and/or atmospheric loads.

Mass balance equations in the form of Equation 1-2 are formulated for each segment in the estuary and for each state-variable included in the modeling framework. This results in $n \times m$ simultaneous finite difference equations to be solved, where n is the number of segments and m is the number of state-variables.

1.1.2 Choice of State Variables

An important criterion for the inclusion of variables in a modeling framework is the existence of adequate field data for calibration/verification of the variable, as well as the importance of the variable in the processes being considered. The kinetic framework employed of the integrated eutrophication is based on the LIS 3.0 eutrophication model developed for the Long Island Sound Study (HydroQual, Inc. 1991), the Massachusetts Bays Eutrophication Model (BEM) developed for the Massachusetts Water Resources Authority (MWRA) and the modeling effort of the Chesapeake Bay system (Cerco and Cole, 1995) and utilizes the following 26 state variables:

1. - salinity (S)
2. - phytoplankton carbon - winter assemblage (P_{c1})
3. - phytoplankton carbon - summer assemblage (P_{c2})
4. - phytoplankton carbon - fall assemblage (P_{c3})
5. - refractory particulate organic phosphorus (RPOP)
6. - labile particulate organic phosphorus (LPOP)
7. - refractory dissolved organic phosphorus (RDOP)
8. - labile dissolved organic phosphorus (LDOP)
9. - algal phosphorus + dissolved inorganic phosphorus (PO_4T)
10. - refractory particulate organic nitrogen (RPON)
11. - labile particulate organic nitrogen (LPON)
12. - refractory dissolved organic nitrogen (RDON)
13. - labile dissolved organic nitrogen (LDON)
14. - algal nitrogen + ammonia nitrogen (NH_4T)
15. - nitrite + nitrate nitrogen (NO_2+NO_3)
16. - biogenic silica - unavailable (SiU)
17. - algal silica + available silica (SiT)
18. - refractory particulate organic carbon (RPOC)
19. - labile particulate organic carbon (LPOC)
20. - refractory dissolved organic carbon (RDOC)
21. - labile dissolved organic carbon (LDOC)
22. - algal exudate dissolved organic carbon (ExDOC)
23. - reactive particulate organic carbon (RePOC)
24. - reactive dissolved organic carbon (ReDOC)
25. - dissolved oxygen equivalents (O_2^*)
26. - dissolved oxygen (DO)

The kinetic equations discussed below incorporate these state variables and are designed to simulate the annual cycle of phytoplankton production, its relation to the supply of nutrients and its effect on dissolved oxygen. The calculation is based on formulating the kinetics which govern the interactions of the

biota and the various nutrient forms, and the application of these kinetics to the waterbody within the context of mass conservation equations.

1.2 MODEL KINETICS

1.2.1 General Structure

Salinity is included in the eutrophicaton modeling framework to enable verification that the transport structure of the hydrodynamic model (Blumberg and Mellor, 1987) is transferred to the water quality model properly. For salinity there are no reaction kinetics involved, i.e., they are conservative. There are no direct sources or sinks of salinity, other than via exchange with the model boundaries or via freshwater dilution resulting from wastewater treatment facility discharges, CSOs, etc. and from freshwater rivers draining into the waterbody.

Figure 1-1 presents the principal kinetic interactions for the nutrient cycles and dissolved oxygen. In the phosphorus system kinetics, dissolved inorganic phosphorus (DIP) is utilized by phytoplankton for growth. Phosphorus is returned from the phytoplankton biomass pool to the various dissolved and particulate organic phosphorus pools and to DIP through endogenous respiration and predatory grazing. The various forms of organic phosphorus are converted to DIP at a temperature dependent rate.

The kinetics of the nitrogen species are fundamentally the same as the kinetics of the phosphorus system. Ammonia and nitrite + nitrate are used by phytoplankton for growth. Ammonia is the preferred form of inorganic nitrogen for algal growth, but phytoplankton will utilize nitrite + nitrate nitrogen as ammonia concentrations become depleted. Nitrogen is returned from algal biomass and follows pathways that are similar to those of phosphorus. Organic nitrogen is converted to ammonia at a temperature dependent rate, and ammonia is then converted to nitrite + nitrate (nitrification) at a temperature and oxygen dependent rate. Nitrite + nitrate may be converted to nitrogen gas (denitrification) in the absence of oxygen at a temperature dependent rate.

Available silica is utilized by diatom phytoplankton during growth. Silica is returned to the unavailable silica pool during respiration and predation and must undergo mineralization processes before becoming available for phytoplankton growth.

Dissolved oxygen is coupled to the other state variables. The sources of oxygen considered are reaeration and algal photosynthesis. The sinks of oxygen are algal respiration, oxidation of detrital carbon and carbonaceous material from wastewater treatment plant effluents and nonpoint discharges, nitrification and SOD.

Organic carbon sources include anthropogenic inputs and the by-products of primary production and zooplankton grazing. The kinetic subroutine also incorporates two highly reactive organic carbon pools that can be used to represent organic carbon inputs from combined sewer overflows (CSOs) and/or waste water treatment plants (WWTPs) with poor treatment performance. The sink of organic carbon is via bacterial decomposition or oxidation. Specific details for the above reactions are presented below.

1.2.2 Phytoplankton Growth and Loss Kinetics

The current implementation of RCA permits the user to simulate up to three functional algal groups. They may represent a winter diatom group, a summer mixed assemblage, a fall mixed assemblage or they may represent a winter diatom group, a late spring/summer green group, and a late summer blue-green species (such as *Microcystis* or *Amabena*). The user, however, does have the option of implementing one, two, or three groups. In case, any kinetic framework employed for all three functional algal groups is the same, only the choice of model coefficients is different. It is convenient to express the kinetic source term for phytoplankton, S_P, as the difference between the phytoplankton growth rate, G_P, and the loss rate, D_P. That is:

$$S_p = (G_p - D_p)P \tag{1-4}$$

where P is the phytoplankton biomass (in units of carbon), and where G_P and D_P have units (day^{-1}). The balance between the magnitude of the growth rate and the loss rate (together with the transport and mixing) determines the rate at which phytoplankton mass is created (or lost) in each volume element.

The growth rate of a population of phytoplankton in a natural environment is a complicated function of the species of phytoplankton present and their differing reactions to solar radiation, temperature, and the balance between nutrient availability and nutrient requirements. In order to construct a growth function, a simplified approach is followed. Rather than consider the problem of different species and their associated environmental and nutrient requirements, the population is characterized as a whole by a measurement of the biomass of the phytoplankton present.

For single species, the direct measure of the population size is the number of cells per unit volume. Cell counts of a single species may be obtained fairly readily in a well-controlled laboratory environment. However, in naturally occurring populations, this measure may be somewhat ambiguous. It is often difficult to distinguish between viable and non-viable cells, and colonizing species tend to pose a problem because counts usually do not distinguish individual cells, and the sizes of the colonies are quite variable.

The sum of the numbers of each species, the total count, could be used to characterize biomass, but since cell size varies substantially, the pico-phytoplankton would dominate such an aggregation. To account for this, the total bio-volume, or wet weight of phytoplankton, assuming unit density, can be calculated using characteristic volumes for each identified species. Unfortunately, volumes can vary appreciably as a function of nutrient availability. Conversion to phytoplankton dry weight and carbon involves further species-dependent constants, which are also nutrient dependent, and, therefore, are subject to variation and uncertainty. Thus, although the use of phytoplankton dry weight or carbon concentration is an appealing solution to the issue of aggregation, it suffers from some practical difficulties.

An alternative approach to this problem is to measure a parameter which is characteristic of all phytoplankton, namely, chlorophyll-a (chl-a), and to use this as the aggregated variable. The principal advantages are that the measurement is direct, it integrates cell types and age, and it accounts for cell viability. The principal disadvantages are that it is a community measurement with no differentiation between functional groups (for example, diatoms or blue-green algae), and it is not necessarily a good measurement of standing crop in dry weight or carbon units, since the chlorophyll to dry weight and

chlorophyll to carbon ratios are variable, and non-active chlorophyll (phaeo-pigments) must be measured to determine viable chlorophyll concentrations.

As can be seen from the above discussion, no simple aggregate measurement is entirely satisfactory. From a historical and practical point of view, the availability of extensive chlorophyll-a data for many waterbodies essentially dictates its use as the aggregate measure of the phytoplankton population, or biomass, for calibration and verification purposes. However, for internal computations, the eutrophication model uses phytoplankton carbon as a measure of algal biomass. The reasons for choosing phytoplankton carbon, rather than chl-a as the internal state variable, are twofold. The first reflects the fact that measures of primary production (an important measure of carbon fixation or growth) are made in carbon units. The second reason is that the use of phytoplankton carbon greatly facilitates the model computation of oxygen-demanding material deposited to the sediment bed via settling.

1.2.2.1 Standard Algal Growth Model

At the current time, HydroQual uses one of two algal growth model formulations. The first of these (to be referred to as the "standard" algal growth model formulation) dates back to the early work of DiToro, O'Connor, and Thomann on the Sacramento-San Joaquin River system (DiToro et al., 1971), the Great Lakes (DiToro and Matystik, 1980, DiToro and Connolly, 1980), and the Potomac Estuary (Thomann et al, 1974, Thomann and Fitzpatrick, 1982). The second algal growth model (to be referred to as the Laws and Chalup model) is based on the model developed by Laws and Chalup (1990) and applied by HydroQual (1995) to the Massachusetts Bays system.

To date, the standard model has been applied by HydroQual to more studies than has the Laws and Chalup model, but we feel there is merit in making both versions of the algal growth model available to the user. The details of the standard model will be presented first, followed by the Laws and Chalup model. These in turn will be followed by a description of the nutrient and dissolved oxygen kinetics.

With the choice of biomass units established, i.e., a carbon based system (mg C/L or gm C/m^3), a growth rate, which expresses the rate of production of biomass as a function of the important environmental variables, temperature, light and nutrients, may be developed. The specific growth rate, G_P, is related to G_{Pmax}, the maximum growth rate at optimum light, temperature and nutrients, via the following equation:

$$G_p = G_{Pmax} \cdot \underbrace{G_T(T)}_{\text{temperature}} \cdot \underbrace{G_I(I)}_{\text{light}} \cdot \underbrace{G_N(N)}_{\text{nutrients}} \qquad (1\text{-}5)$$

where
$G_T(T)$ is the effect of temperature, $G_I(I)$ is the light attenuation given by

$$G_I(I) = g(I, f, H, k_e) \qquad (1\text{-}6)$$

and $G_N(N)$ is the nutrient limitation given by

$$G_N(N) = g(DIP, DIN, Si) \qquad (1\text{-}7)$$

where T is the ambient water temperature; I is the incident solar radiation; f is the fraction of daylight; H is the depth of the water column; k_e is the extinction or light attenuation coefficient; and DIP, DIN and Si are the available nutrients required for growth, dissolved inorganic phosphorus (ortho-phosphate), dissolved inorganic nitrogen (ammonia plus nitrite/nitrate) and dissolved available silica, respectively.

Initial estimates of G_{Pmax} are generally based upon the literature and/or previous modeling studies and are subsequently refined during the calibration process. During the simulation, the selected maximum growth rates are temperature corrected using spatially-dependent, time-dependent water column temperature values as computed by the hydrodynamic model. The temperature corrected growth rate is computed using one of the two following equations, which relates $G_{Pmax}(T)$, the growth rate at ambient temperature, T, to $G_{Pmax}(T_{20})$ the growth rate at 20°C (via equation (1-8a)) or to $G_{Pmax}(T_{opt})$, the growth rate at the optimal temperature, T_{opt} (via equations (1-8b) and (1-8c)):

$$G_{P\max}(T) = G_{P\max}(T_{20})\ \theta^{T-20} \qquad (1\text{-}8a)$$

$$G_{P\max}(T) = G_{P\max} e^{-\beta_1 (T_{opt}-T)^2} \qquad T \le T_{opt} \qquad (1\text{-}8b)$$

or

$$G_{P\max}(T) = G_{P\max} e^{-\beta_2 (T_{opt}-T)^2} \qquad T > T_{opt} \qquad (1\text{-}8c)$$

where θ is the Arrenhius temperature coefficient, and β_1 and β_2 are shaping coefficients. When using equations 1-8b and 1-8c to temperature correct G_{Pmax}, T_{opt} has a much lower value for winter diatoms then would be used for the summer mixed assemblage. It is suggested to utilize the Arrenhius formulation when modeling one functional algal group and the shaped formulation when modeling two or more functional groups.

Figure 1-2 presents comparisons of the two temperature correction formulations. In Figure 1-2a, the normalized growth rates are compared for the Arrenhius (normalized to the 20°C growth rate versus the shaped formulation (normalized to the maximum growth rate at the optimum temperature) for a winter temperature optimum of 8°C and a summer temperature optimum of 24°C. Figure 1-2b presents a similar comparison but for "actual" growth rates of 1.7, 2.2, and 3.0 day for the Arrenhius, winter-shaped, and summer-shaped formulations. The temperature corrected growth rate is then adjusted to reflect effects due to ambient light and nutrient levels.

In the natural environment, the light intensity to which the phytoplankton are exposed is not uniformly at the optimum value. At the surface and near-surface of the air-water interface, photo-inhibition can occur due to high light intensities, while at depths below the euphotic zone, light is not available for photosynthesis due to natural and algal related turbidity. The light formulation included in the standard RCA modeling framework extends from a light curve analysis by Steele (1962) and accounts for both the effects of saturating light intensities and light attenuation through the water column. The depth-averaged light attenuated growth rate factor, $G_I(I)$, is presented in Equation 1-9 and is obtained by integrating the specific growth rate over depth:

where:

$$G_I(I) = \frac{e}{k_e H}\left[\exp\left(\frac{-I_o(t)}{I_s}e^{-k_e H}\right) - \exp\frac{-I_o(t)}{I_s}\right] \quad (1\text{-}9)$$

e = 2.718
H = the water column depth or thickness of the water cell or segment (m),
k_e = the total extinction coefficient, $k_{ebase} + k_c P_{chl\text{-}a}$ computed from the sum of the base, non-algal related, light attenuation, k_{ebase}, and the self-shading attenuation due to the ambient phytoplankton population $k_c P_{chl\text{-}a}$ (m^{-1}),
k_c = the algal related extinction coefficient per unit of chlorophyll (m^2/mg chl-a),
$P_{chl\text{-}a}$ = the ambient phytoplankton population as chlorophyll (mg chl-a/L), where $P_{chl\text{-}a} = P_c/a_{cchl}$
P_c = the ambient phytoplankton population as carbon (mg C/L),
a_{cchl} = the ratio of algal carbon to algal chlorophyll (mg C/mg chl-a),
I_o = the incident light intensity at the segment surface (ly/day),
I_s = the saturating light intensity (ly/day).

The value of I_o at the water surface, I_{surf}, may be evaluated at any time, t, within the day using the following formula:

$$I_{surf}(t) = \frac{I_{tot}}{0.635\,f}\sin\left[\frac{\pi(t_d - t_{sunrise})}{f}\right] \quad (1\text{-}10)$$

where
I_{tot} = total daily incident solar radiation (ly/day),
f = fraction of daylight (daylight hours/24),
t_d = time of day,
$t_{sunrise}$ = time of sunrise

To account for the effect of variations of available light as a function of depth, the light intensity, I_o (H), at any depth, H, is related to the incident surface intensity, I_{surf}, via the extinction coefficient, k_e through the formula

$$I_o(H) = I_{surf}\exp^{-k_e H} \quad (1\text{-}11)$$

The effects of various nutrient concentrations on the growth of phytoplankton have been investigated, and the results are quite complex. As a first approximation to the effect of nutrient concentration on the growth rate, it is assumed that the phytoplankton population in question follows Monod growth kinetics with respect to the important nutrients. That is, at an adequate level of nutrient concentration, the growth rate proceeds at the saturated rate for the ambient temperature and light conditions. However, at low nutrient concentration, the growth rate becomes linearly proportional to nutrient concentration. Thus, for a nutrient with concentration N_j in the jth segment, the factor by which the saturated growth rate is reduced in the jth segment is $N_j/(K_m + N_j)$. The constant, K_m, which is called the Michaelis or half-saturation constant, is the nutrient concentration at which the growth rate is half the saturated growth rate. Since there are three nutrients, nitrogen, phosphorus and silica, considered in this

framework, the Michaelis-Menton expression is evaluated for each nutrient and the minimum value is chosen to reduce the saturated growth rate,

$$G_N(N) = \text{Min}\left(\frac{DIN}{K_{mN}+DIN}, \frac{DIP}{K_{mP}+DIP}, \frac{Si}{K_{mSi}+Si}\right) \quad (1\text{-}12)$$

Numerous mechanisms have been proposed which contribute to the death rate of phytoplankton: endogenous respiration, grazing by herbivorous zooplankton, sinking or settling from the water column and parasitization (Fogg, 1965). The first three mechanisms have been included in previous models for phytoplankton dynamics and they have been shown to be of general importance. For this version of the integrated eutrophication model, only endogenous respiration and settling have been explicitly included in the modeling framework. The effect of zooplankton grazing is included indirectly using a first-order temperature corrected algal loss rate.

The endogenous respiration rate of phytoplankton is the rate at which the phytoplankton oxidize their organic carbon to carbon dioxide per unit weight of phytoplankton organic carbon. Respiration is the reverse of the photosynthesis process, and as such, contributes to the loss rate of the phytoplankton population. If the respiration rate of the phytoplankton, as a whole, is greater than the growth rate, there is a net loss of phytoplankton carbon or biomass. The endogenous respiration rate has been shown to be temperature dependent (Riley et al., 1949) and historically has been included in eutrophication models using Equation 1-13a,

$$k_{PR}(T) = k_{PR}(20^oC) \cdot \theta_{PR}^{(T-20)} \quad (1\text{-}13a)$$

where k_{PR} (20°C) is the endogenous respiration rate at 20°C, and k_{PR}(T) is the temperature corrected rate. The units of k_{PR} are day^{-1}.

However, more recently the literature (Laws and Bannister, 1980, Laws and Chalup, 1991) suggests that algal respiration should be divided into two components - basal or resting respiration and respiratory losses associated with photosynthesis. This may be written mathematically as follows:

$$k_{PR}(T) = r_g G_P + r_b \theta_{PR}^{T-20} \quad (1\text{-}13b)$$

where r_g is the fraction of the algal growth (G_P) lost to the energy cost of photosynthesis and r_b is the basal respiration rate. Note, the user can select either form of the respiration rate equation when performing a simulation. If the user wishes to use the first formulation (equation 1-13a) then set r_g equal to zero and use an appropriate value for r_b (~0.1-0.3/day). If the user wises to use the latter form (equation 1-13b) then set r_g to a non-zero value (0.1-0.3) and use a lower value (0.01-0.03/day) for r_b.

The sinking or settling of phytoplankton is an important contribution to the overall mortality of the phytoplankton population, particularly in lakes and coastal oceanic waters. Published values of the sinking velocity of phytoplankton, mostly in quiescent laboratory conditions, range from 0.1 to 18.0 m/day. However, in some instances for certain species, such as dinoflagellates or buoyancy-retulating blue-greens, the settling velocity may be zero or negative. Furthermore, actual settling rates in natural waters are a complex phenomenon, affected by vertical turbulence, density gradients and the physiological state of the

different species of phytoplankton. An important factor determining the physiological state of algae is nutrient availability. Bienfang et al. (1982) measured sinking rate response of four marine diatoms to depletion of nitrate, phosphate and silicate. All four species showed significant increase in sinking rate under conditions of silica depletion; one species showed increased settling rate under nitrate limitation. An analysis of field experiments by Culver and Smith (1989) indicated that low concentrations of nitrate, as well as light availability, affected diatom settling rates. Although the effective settling rate of phytoplankton is greatly reduced in a relatively shallow, well-mixed river or estuary, due to vertical turbulence, it still can contribute to the overall mortality of the algal population. In addition, the settling phytoplankton can be a significant source of nutrients to the sediments and can play an important role in the generation of SOD. For these reasons, a temperature- dependent term representing phyto-plankton settling has been included in the algal mortality expression, and may be written as follows:

$$k_{sP} = \left[\frac{V_{sPb}}{H} + \frac{V_{sPn}}{H} \cdot \left(1 - G_N(N)\right) \right] \cdot \theta_{base}^{(T-20)} \tag{1-14}$$

where k_{sP} is the net effective algal loss rate due to settling (day^{-1}), v_{sPb} is the base settling velocity of phytoplankton (m/day), v_{sPn} is the nutrient dependent settling rate, (m/day), $G_N(N)$ is defined by Equation 1-12, and H is the depth of the segment, (m).

Zooplankton grazing may, depending upon time of the year and zooplankton biomass levels, be an important loss rate for phytoplankton. The loss term used to represent zooplankton grazing is as follows:

$$k_{grz}(T) = k_{grz}(20^{o}C) \cdot \theta_{grz}^{(T-20)} \tag{1-15}$$

where $k_{grz}(T)$ is the temperature corrected loss rate due to zooplankton grazing and $k_{grz}(20°C)$ is the predation rate at 20°C. The units of k_{grz} are day^{-1}.

The total loss rate for phytoplankton is the sum of the three loss rates described above:

$$D_P = k_{PR}(T) + k_{sP} + k_{grz}(T) \tag{1-16}$$

This completes the specification of the growth and death rates for phytoplankton (for the standard algal growth model) in terms of the physical variables: light, temperature and available nutrients. Table 1-1 summarizes the equations and model coefficients used in the standard version of the eutrophicaton model.

TABLE 1-1. STANDARD PHYTOPLANKTON GROWTH EQUATIONS

Phytoplankton Net Growth Rate

$$S_p = \left(G_{P\max} \cdot G_T(T) \cdot G_I(I) \cdot G_N(N) - k_{PR}(T) - k_{sP} - k_{grz}(T)\right) \cdot P_c$$

Temperature Correction

Arrenhius Version

$$G_{Pmax}(T) = G_{Pmax}\ \theta_P^{(T-20)}$$

Optimum Temperature Version

$$G_{Pmax}(T) = G_{Pmax} e^{-\beta_1 (T-T_{opt})^2} \qquad T \le T_{opt}$$

$$G_{Pmax}(T) = G_{Pmax} e^{-\beta_2 (T_{opt}-T)^2} \qquad T > T_{opt}$$

Murderkill River Model

Light Reduction

$$G_I(I) = \frac{e}{k_e H}\left[\exp\left(\frac{-I_o(t)}{I_s} e^{-k_e H}\right) - \exp\frac{-I_o(t)}{I_s}\right]$$

Is = 350 ly/d

$$k_e = k_{e_{base}} + k_c \cdot a_{cchl} \cdot P_c$$

Nutrient Uptake

$$G_N(N) = \text{Min}\left(\frac{DIN}{K_{mN}+DIN}, \frac{DIP}{K_{mP}+DIP}, \frac{Si}{K_{mSi}+Si}\right)$$

DIN = dissolved inorganic nitrogen = NH_4 + NO_2+NO_3,
DIP = dissolved inorganic phosphorus (PO_4),
Si = available silica

Algal Respiration

$$k_{PR}(T) = k_{PR}(20^oC) \cdot \theta_{PR}^{(T-20)}$$

or

$$k_{PR}(T) = r_g G_P + r_b \theta_{PR}^{(T-20)}$$

Algal Settling

$$k_{sP} = \left[\frac{V_{sPb}}{H} + \frac{V_{sPn}}{H} \cdot \left(1 - G_N(N)\right)\right] \cdot \theta_{base}^{(T-20)}$$

TABLE 1-1. STANDARD PHYTOPLANKTON NET GROWTH EQUATIONS
(Continued)

Zooplankton Grazing

$$k_{grz}(T) = k_{grz}(20^{o}C) \cdot \theta_{grz}^{(T-20)}$$

Exogenous Variables

Description	Notation
Total Extinction Coefficient	k_e
Base Extinction Coefficient	k_{ebase}
Total Daily Surface Solar Radiation	I_o
Temperature	T
Segment Depth	H

Rate Constants

Description	Notation	Winter Diatoms	Summer Assemblage	Units	Murderkill River Model
Maximum Specific Growth Rate at T_{opt}	G_{Pmax}	1.7-2.5	2.0 - 3.0	day^{-1}	2.5
Temperature Coefficient	θ_P	1.068	1.068		1.068
Temperature Optimum	T_{opt}	6-12	20 - 25	°C	25
Shaping parameters	β_1, β_2	0.003-0.006	0.003-0.006		0.004-0.006
Phytoplankton Self-Light Attenuation	k_c	0.017	0.017	m^2/mg chl-a	0.017
Half-Saturation Constant for Nitrogen	K_{mN}	10.	10.	µgN/L	10
Half-Saturation Constant for Phosphorus	K_{mP}	1.	1.	µgP/L	1
Half-Saturation Constant for Silica	K_{mSi}	20.	2.	µgSi/L	20
Respiration Rate	$k_{PR}(20^oC)$	0.1-0.3	0.1-0.3	day^{-1}	
Temperature Coefficient	θ_{PR}	1.047-1.068	1.047-1.068		1.068
Cost of Photosynthesis	r_g	0.2 - 0.3	0.2 - 0.3		0.3
Basal Respiration	r_b	0.01-0.03	0.01-0.03	/day	0.05
Base Algal Settling Rate	v_{sPb}	0.2-1.0	0.2-1.0	m/day	0.3
Nutrient Dependent Algal Settling Rate	v_{sPn}	0.5-1.0	0.5-1.0	m/day	0.0
Temperature Coefficient	θ_{base}	1.029	1.029		1.027
Loss Due to Zooplankton Grazing	$k_{grz}(20^oC)$	0.05-0.10	0.05-0.10	/day	0.025
Temperature Coefficient	θ_{grz}	1.10	1.10		1.10
Carbon/Chlorophyll Ratio	a_{cchl}	30-60.	75-100.	mgC/mg chl-a	40

1.2.2.2 Laws-Chalup Algal Growth Model

The second algal growth model available in this release of RCA draws directly from Laws and Chalup (1990) and an earlier modeling framework developed by Shuter (1979). The following paragraphs provide an overview of the Laws-Chalup model. In the Laws-Chalup model, the carbon in the phytoplankton cell is considered to be found in one of four compartments: structural carbon (S), reservoir or storage carbon (R), carbon associate with the light reactions (photochemical reactions) of photosynthesis (L), or carbon associated with the dark reactions (carbohydrate production and protein and lipid synthesis) of photosynthesis (D). Hence, total cell carbon, C = S + R + L + D. Chlorophyll is assumed to exist only in the L portion of the cell. Nutrients (nitrogen, phosphorus, and silica) are found in the S, L, and D portions of the cell and are assumed to be found in the same ratios in each of these pools. R is assumed to consist entirely of C storage products (carbohydrates and lipids) and hence contains no nutrients. The fraction of C allocated to structural purposes (S/C) is assumed to be constant and independent of growth conditions.

The steady-state gross photosynthetic rate per cell (ρ) is described by

$$\rho = G_{prl}\ L\ I = G_{prd}\ D \tag{1-17}$$

where I is the incident irradiance; G_{prd} is the gross photosynthetic rate per unit D and is a constant; and G_{prl} is the gross rate of photosynthesis per unit L per unit light intensity and is a function of environmental conditions. Respiration losses are assumed to be described by

$$k_{PR} = k_{RB} + k_{RG}\ G_{prd}\ D \tag{1-18}$$

where k_{RB} is the basal respiration rate per cell, i.e., the rate required to maintain the cell in the absence of growth, and k_{RG} is the growth-rate-dependent respiration coefficient (Laws and Bannister, 1980). The substrate for respiration is assumed to come from the R pool.

From the foregoing assumptions, it follows that the rate of nutrient assimilation f_N is constrained by

$$\frac{d}{dt}(S+L+D) = W_{Nx}\ f_N \tag{1-19}$$

where W_{Nx} is the ratio of C to nutrient x (either nitrogen, phosphorus or silica). It also follows that

$$\frac{dC}{dt} = G_{prd}\ D - k_{RB} - k_{RG}\ G_{prd}\ D \tag{1-20}$$

Under conditions of balanced growth it must be true that for any component X of the cell,

$$\mu = \frac{1}{X}\frac{dX}{dt} \tag{1-21}$$

where μ is the growth rate in units of inverse time. Combining Equations (1-20) and (1-21) yields

$$\mu C = G_{prd} D - k_{RB} - k_{RG} G_{prd} D \quad (1\text{-}22)$$

Laws and Chalup also define the assumptions and conditions under which a nutrient saturated version of Equation 1-22 can be developed. The nutrient saturated growth rate, μ_{Pmax}, is of the form

$$\mu_{P\max} = \frac{G_{prd}(1-k_{RG})(1-S/C)I}{I + G_{prd}/G_{prls}} - \frac{k_{RB}}{C} \quad (1\text{-}23)$$

where G_{prls} is the nutrient-saturated value of G_{prl}. Laws and Chalup then account for the relationship between light and G_{prls} by use of Equation (1-24).

$$G_{prls} = \frac{G_{prlo}}{1 + I/I_s} \quad (1\text{-}24)$$

where G_{prlo} is the value of G_{prls} when I = 0, and Is is the value of I when $G_{prls} = 0.5G_{prlo}$.

As described in Section 1.2.2.1 Standard Algal Growth Model, in the natural environment, the light intensity or incident irradiance, I, to which the phytoplankton are exposed is not uniformly at the optimum value. The variations in light exposure that phytoplankton are exposed to due to position in the water column and daily variations to solar radiation that were detailed in Section 1.2.2.1 also apply in the Laws-Chalup growth model. Equations (1-10) and (1-11) are used to determine the diurnal variation in solar radiation at the surface of the water column, given the total solar radiation, and its attenuation through the water column, respectively.

One additional parameterization that is incorporated in the Laws-Chalup formulation is photo-adaptation by phytoplankton. Phytoplankton have been shown to be able to adapt to variations in light intensity (Steemann Nielsen et al., 1962; Steemann Nielsen and Park, 1964; Morel et al. 1987). Experimental data have indicated that phytoplankton may take several hours to two to four days to adapt to changes in light intensity. Therefore, the value of I_s, in Equation 1-24 is permitted to change as a function of the antecedent light history, according to the formula:

$$I_s = \left(I_{tot_{n-3}} + I_{tot_{n-2}} + I_{tot_{n-1}}\right)/3 \quad (1\text{-}25)$$

where:

$I_{tot_{n-3}}$ = total solar radiation three days preceding current model day,
$I_{tot_{n-2}}$ = total solar radiation two days preceding current model day,
$I_{tot_{n-1}}$ = total solar radiation one day preceding current model day.

Note: the use of the photo-adaptation formula is optional. If the user wishes to include photo-adaptation then he or she should set the appropriate I_{sat} in the "Constants" section of the model input to zero. Otherwise, if a non-zero value for I_{sat} is specified then photo-adaptation is ignored the user specified value for I_{sat} is applied in equations (1-9) or (1-24).

The nutrient saturated growth rate is then temperature-corrected using spatially dependent, time-dependent values of ambient water column temperature as computed by the hydrodynamic model. The temperature-corrected growth rate is computed usng either equation 1-8a or equations 1-8b and 1-8c. A principal difference between the winter diatom group and the summer assemblage is that the winter group has a much lower T_{opt} than does the summer assemblage. The nutrient saturated, temperature-corrected growth rate is then adjusted to reflect effects due to nutrient levels, as described earlier (Equation 1-12). Table 1-2 presents the equations used for algal growth for the Law-Chalup version of algal growth.

TABLE 1-2. LAWS-CHALUP PHYTOPLANKTON GROWTH EQUATIONS

Phytoplankton Net Growth Rate

$$S_p = (\mu_{Pmax}(T,I) \cdot G_N(N) - k_{RB} - k_{sP}(T) - k_{grz}(T)) \cdot P_c$$

Specific Growth Rate

$$G_p = \mu_{Pmax}(T,I) \cdot G_N(N)$$

Nutrient Saturated Growth Rate

$$\mu_{Pmax}(T_{opt}, I) = \frac{G_{prd} \cdot (1 - k_{RG}) \cdot (1 - S/C) \cdot I(z,t)}{G_{prd}/G_{prlo} + I(z,t)\ (1 + G_{prd}/I_s G_{prlo})} - k_{RB}$$

Temperature Correction

$$\mu_{Pmax}(T) = \mu_{Pmax}(T_{opt}) \cdot e^{-\beta_1 \cdot (T - T_{opt})^2} \qquad T \le T_{opt}$$

$$\mu_{Pmax}(T) = \mu_{Pmax}(T_{opt}) \cdot e^{-\beta_2 \cdot (T - T_{opt})^2} \qquad T > T_{opt}$$

Light Attenuation

$$I(z,t) = I_{surf}(t)\, e^{-k_e z}$$

Average Light

$$I_{ave} = \frac{I_{surf}(t)}{k_e H}\left(1 - e^{-k_e H}\right)$$

$$k_e = k_{e_{base}} + k_c \cdot a_{ChlC} \cdot P_c$$

$$I_{surf}(t) = \frac{I_{tot}}{0.635 \cdot f} \sin\left(\frac{\pi\left(t_d - t_{sunrise}\right)}{f}\right)$$

$$I_s = \left(I_{tot_{n-3}} + I_{tot_{n-2}} + I_{tot_{n-1}}\right)/3$$

TABLE 1-2. LAWS-CHALUP PHYTOPLANKTON GROWTH EQUATIONS (CONTINUED)

Chlorophyll to Carbon Ratio (a_{ChlC})

$$a_{ChlC} = \frac{1-(1-QF)(1-\mu/\mu_{Pmax})-S/C-(\mu+k_{RB}/C)/\left[(1-k_{RG})G_{prd}\right]}{W_{CChl}}$$

Nutrient Uptake

$$G_N(N) = Min\left(\frac{DIN}{K_{mN}+DIN}, \frac{DIP}{K_{mP}+DIP}, \frac{Si}{K_{mSi}+Si}\right)$$

DIN = dissolved inorganic nitrogen = NH_3 + NO_2 + NO_3
DIP = dissolved inorganic phosphorus
Si = available silica

Endogenous Respiration

$$k_{PR} = \frac{k_{RB}+k_{RG}\cdot\mu}{1-k_{RG}}$$

$$\mu = G_N(N)\cdot\mu_{Pmax}$$

Algal Settling

$$k_{sP}(T) = \left(\frac{v_{sPb}}{H} + \frac{v_{sPn}}{H}\cdot(1-G_N(N))\right)\cdot\theta_{sP}^{(T-20)}$$

Zooplankton Grazing

$$k_{grz}(T) = k_{grz}(20^oC)\cdot\theta_{grz}^{(T-20)}$$

TABLE 1-2. LAWS-CHALUP PHYTOPLANKTON GROWTH EQUATIONS (CONTINUED)

Exogenous Variables

Description	Notation	Units
Total Extinction Coefficient	k_e	m^{-1}
Base Extinction Coefficient	k_{ebase}	m^{-1}
Total Daily Surface Solar Radiation	I_{tot}	langleys/day
Temperature	T	°C
Segment Depth	H	m
Fraction of Daylight	f	day
Time of Day	t_d	day
Time of Sunrise	$t_{sunrise}$	day

Rate Constants

Description	Notation	Winter Diatoms	Summer Assemblage	Units
Gross photosynthetic rate per unit D	G_{prd}	2.5	3.0	day^{-1}
Gross photosynthetic rate per unit L per unit light intensity in the limit of zero irradiance	G_{prlo}	0.28	0.28	m^2/mol quanta
Quotient of nutrient to carbon ratios at relative growth rates of 0 and 1	QF	0.85	0.85	
Effect of Temperature below T_{opt} on growth	β_1	0.004	0.004	
Effect of Temperature above T_{opt}	β_2	0.006	0.006	
Temperature Optimum	T_{opt}	8.	18.	°C
Phytoplankton Self-Shading Attenuation	k_c	0.017	0.017	m^2/mg chl-a
Half-Saturation Constant for Nitrogen	K_{mN}	0.010	0.010	mg N/L
Half-Saturation Constant for Phosphorus	K_{mP}	0.001	0.001	mg P/L
Half-Saturation Constant for Silica	K_{mSi}	0.020	0.005	mg Si/L
Growth Related Respiration Coefficient	k_{RG}	0.28	0.28	
Basal Respiration Rate	k_{RB}	0.03	0.036	day^{-1}
Base Algal Settling Rate	v_{sPb}	0.5	0.3	m/day
Nutrient Dependent Algal Settling Rate	v_{sPn}	1.0	0.7	m/day
Temperature Coefficient	θ_{sP}	1.027	1.027	
Loss Due to Zooplankton Grazing	k_{grz} (20°C)	0.1	0.1	day^{-1}
Temperature Coefficient	θ_{grz}	1.10	1.10	
Nutrient Saturated Carbon/Chlorophyll Ratio in L	W_{CChl}	40.	65.	mg C/mg chl-a
Ratio of Structural to Total Carbon	S/C	0.1	0.1	

1.2.3 Stoichiometry and Uptake Kinetics

A principal component in the mass balance equations for the nutrient systems included in the eutrophication framework is the nutrient uptake kinetics associated with algal growth (as defined via equations (1-5) through (1-25)). In order to quantify the nutrient uptake it is necessary to specify the population stoichiometry in units of nutrient uptake per mass of population synthesized. For carbon as the unit of population biomass, the relevant ratios are the mass of nitrogen, phosphorus and silica per unit mass of carbon.

This version of the integrated eutrophication model includes two variable algal stoichiometry formulations as well as the more traditional constant stoichiometry formulation. The variable stoichiometry formulation allows internal algal nutrient levels to vary as a function of the external nutrient levels. This process is sometimes referred to as "luxury nutrient uptake". That is, when external nutrient levels are in surplus the internal nutrient to carbon ratio increases thereby allowing internal storage of nutrients. The reverse occurs when external nutrient levels are low and are approaching the nutrient half saturation constant. In this case, the internal nutrient to carbon ratios decrease and the algal cell can continue to grow at low external nutrient levels.

1.2.3.1 Algal Stoichiometry and Uptake Kinetics - Standard Algal Growth Model

As mentioned above, two forms of variable nutrient stoichiometry are included in the integrated eutrophication model. The first is based on an emphirical formulation developed for the Chesapeake Bay model (Cerco, 1995). This formulation is presented graphically in Figure 1-3 for the carbon to phosphorus ratio from measurements collected in upper Chesapeake Bay.

A generalized variable stoichiometry formulation, based on the Chesapeake Bay model, may be written for a dissolved nutrient (DIX) as follows:

$$\frac{C}{X} = X_1 + (X_2 - X_1)e^{-X_3 \cdot DIX} \qquad (1\text{-}26)$$

where:

$\frac{C}{X}$ = carbon to nutrient ratio,

X_1 = nutrient saturated, carbon to nutrient ratio,

X_2 = nutrient limited, carbon to nutrient ratio (maximum),

X_3 = coefficient that determines the rate at which the carbon to nutrient ratio changes as a function of the ambient nutrient concentration, DIX,

DIX = dissolved concentration of available nutrient (either DIN, DIP, or DSi).

Table 1-3 lists the range in nitrogen, phosphorus and silica variable-stiochiometry coefficients used in previous modeling studies conducted by HydroQual.

TABLE 1-3. VARIABLE STOICHIOMETRY COEFFICIENTS - STANDARD ALGAL GROWTH MODEL

	Winter Assemblage	Summer Assemblage	Murderkill River Model
Nitrogen			
CRBN1 (mgC/mgN)	5.2-5.67	4-5.67	5.67
CRBN2 (mgC/mgN)	6.5-7.20	7.5-10.0	10.0
CRBN3 (L/mgN)	10-15	10-15	10.0
Phosphorus			
CRBP1 (mgC/mgP)	25-40	25-40	40.0
CRBP2 (mgC/mgP)	90	90	90.0
CRBP3 (L/mgP)	100-200	40-200	100.0
Silica			
CRBS1 (mgC/mgSi)	2.2-3.0	5.-10.	7.5
CRBS2 (mgC/mgSi)	8-15	10-25	17.50
CRBS3 (L/mgSi)	12-30	5-10	7.5

1.2.3.2 Algal Stoichiometry and Uptake Kinetics - Laws-Chalup Algal Growth Model

Lacking extensive measurements of the particulate forms of carbon, nitrogen, phosphorus and biogenic silica, many modeling studies have assumed that phytoplankton are comprised of carbon and nutrients which approximate Redfield ratios; i.e., 106C:16N:1P (atomic), under nutrient saturated conditions. However, while the use of Redfield ratios may be appropriate under nutrient saturated conditions, it has been shown (Anita et al., 1963; Caperon and Meyer, 1972; Chalup and Laws, 1990) that algae change their cellular composition or stoichiometry as a function of nutrient status. This is accounted for in the Laws/Chalup model via the following equations:

$$N_x : C = \left[QF + (1 - QF)\,(\mu / \mu_{P\max}\right] / W_{Cx}$$

$$= 1 / W_{Cx} \quad \text{when } \mu = \mu_{P\max} \tag{1-27}$$

and

$$Chl:C = \frac{1-(1-QF)\,(1-\mu/\mu_{Pmax})-S/C-(\mu+k_{RB}/C)/\left[(1-k_{RG})\,G_{prd}\right]}{W_{chl}} \quad (1\text{-}28)$$

$$= \left\{1-S/C-(\mu_{Pmax}+k_{RB}C)/\left[(1-k_{RG})\,G_{prd}\right]\right\}/W_{chl} \text{ when } \mu=\mu_{Pmax}$$

where:

N_x:C = the ratio of nutrient x (nitrogen, phosphorus or silica) to carbon,
QF = quotient of N_x:C values at relative growth rates of 0 and 1,
μ = the nutrient corrected growth rate ($\mu = \mu_{Pmax}\,GN(N)$),
W_{Cx} = the ratio of C to nutrient x in S, L, D,
Chl:C = the ratio of chlorophyll-a to C in P,
W_{Chl} = the ratio of C to chlorophyll-a in P.

The latter equation accounts for changes in the chlorophyll to carbon ratio both as a function of nutrient status and light. Equations 1-27 and 1-28 provide the equilibrium carbon to nutrient and carbon to chlorophyll ratios. However, as has been shown from experimental studies, there is a time period over which it takes the phytoplankton to reach new equilibrium conditions in response to changes in nutrient status and/or available light. This is accounted for by use of the following equations:

$$\frac{dN_x:C^n}{dt} = k_{eq}\left(N_x:C^n_{eq} - N_x:C^n\right) \quad (1\text{-}29)$$

$$N_x:C^{n+1} = N_x:C^n + dt\,\frac{dN_x:C^n}{dt} \quad (1\text{-}30)$$

and

$$\frac{dChl:C^n}{dt} = k_{eq}\left(Chl:C^n_{eq} - Chl:C^n\right) \quad (1\text{-}31)$$

$$Chl:C^{n+1} = Chl:C^n + dt\,\frac{dChl:C^n}{dt} \quad (1\text{-}32)$$

where:

$N_x:C^n$, $N_x:C^{n+1}$ = the nutrient to carbon ratios at time step n and n+1, respectively,
$N_x:C^n_{eq}$ = the equilibrium nutrient to carbon ratio at time step n, as determined from Equation 1-27,
k_{eq} = a constant which determines the time to achieve equilibrium,
$Chl:C^n$, $Chl:C^{n+1}$ = the chlorophyll to carbon ratios at time step n and n+1, respectively,
$Chl:C^n_{eq}$ = the equilibrium chlorophyll to carbon ratio at time step n, as determined from Equation 1-28,
dt = length of time step.

The Laws-Chalup algal growth model evaluates the nutrient to carbon and chlorophyll to carbon ratios to be used form the next time level based on the ratios at the current time level and the equilibrium ratios, determined from Equations 1-27 and 1-28, based upon environmental conditions at the current time level. A value of 1/day was chosen for k_{eq}, based on the literature (Steeman Nielsen and Park, 1964; Anita et al., 1963; Caperon and Meyer, 1972). This corresponds to an equilibrium time of approximately 3 days. This

value has been "hard-wired" in the computer code. Table 1-4 contains the stoichiometric coefficients used in the Massachusetts Bays application of RCA.

TABLE 1-4 VARIABLE STOICHIOMETRY COEFFICIENTS - LAWS-CHALUP ALGAL GROWTH MODEL

	Winter Assemblage	Summer Assemblage
Nitrogen		
W_{CN}	5.67 (6.67[(1)] - 16.2[(2)])	5.67 (6.67[(1)] - 16.2[(2)])
Phosphorus		
W_{CP}	40.(47[(1)] - 114[(2)])	40.(47[(1)] - 114[(2)])
Silica		
W_{csi}	2.5(2.94[(1)] - 7.14[(2)])	7.0(8.2[(1)] - 20.[(2)])
QF quotient of nutrient to carbon ratio at relative growth rates of 0 and 1	0.85[(1)]	0.85[(1)]

(1) maximum C to nutrient ratio at nutrient-limiting conditions using Massachusetts Bays model coefficient of 0.85 for QF

(2) maximum C to nutrient ratio at nutrient-limiting conditions using Laws-Chalup (1990) model coefficient f 0.35 for QF

Figure 1-4 presents a comparison of the carbon to nitrogen ratios obtained using the standard eutrophication variable stoichiometry foundation (Eqn. 1-26) using coefficients used in HydroQual studies versus that proposed by Laws and Chalup (Eqn. 1-27). It is important to note, however, that the coefficient set used by Laws and Chalup was for a single algal species and that a coefficient set that did not produce as sharp a curve was used by HydroQual in its Massachusetts Bay study (1995, 2003).

1.2.3.3 Nutrient Cycling

Once the stoichiometric ratios have been determined, the mass balance equations may be written for the nutrients in much the same way as for the phytoplankton biomass. The principal processes determining the distribution of nutrients among the various pools are: the uptake of inorganic nutrients by phytoplankton for cell growth, the release of organic nutrients by algal respiration and predation processes, and the recycling of organic nutrients to inorganic forms via bacterial hydrolysis and mineralization.

In their work on Lake Huron and Saginaw Bay, Di Toro and Matystick (1980) proposed a nutrient recycle formulation that was a function of the localized phytoplankton population. Drawing from an analysis of available field data and citing the work of others (Hendry, 1977; Lowe, 1976; Henrici, 1938; Menon et al., 1972; and Rao, 1976) that indicated bacterial biomass increased as phytoplankton biomass increased, the mechanism chosen, saturating recycle, was a compromise. This compromise was between the conventional first-order temperature corrected mechanism and a second-order recycle mechanism, in which

the recycle rate is directly proportional to the phytoplankton biomass present, as indicated in pure culture, bacteria seeded laboratory studies (Jewell and McCarty 1971). The various relationships may be written:

$$\text{First} - \text{order recycle}: \quad k(T) = k'(20^{o}C)\,\theta^{T-20} \tag{1-33a}$$

$$\text{Second} - \text{order recycle}: \quad k(T) = k''(20^{o}C)\,\theta^{T-20} \cdot P_c \tag{1-33b}$$

$$\text{Saturating recycle}: \quad k(T) = k'(20^{o}C)\,\theta^{T-20} \cdot \frac{P_c}{K_{mP_c} + P_c} \tag{1-33c}$$

Saturating recycle permits second-order dependency at low phytoplankton concentrations, when $P_c << K_{mPc}$, where K_{mPc} is the half saturation constant for recycle. It also permits first-order recycle when the phytoplankton concentrations greatly exceed the half saturation constant. Basically, this mechanism employs a second order recycle that slows the recycle rate if the algal population is small, but does not permit the rate to increase continuously as phytoplankton concentrations increase. The assumption is that at higher population levels, other factors are limiting the recycle kinetics so that it proceeds at its maximum first-order rate.

1.2.3.4 Organic Carbon

Seven organic carbon state variables are considered: reactive particulate organic (RePOC), reactive dissolved organic (ReDOC), labile dissolved (LDOC), refractory dissolved (RDOC), labile particulate (LPOC), refractory particulate (RPOC) and dissolved algal exudate (ExDOC). Reactive, labile and refractory distinctions are based upon the time scale of oxidation or decomposition. Reactive organic carbon decomposes on a time scale of days to a week or two and is meant to be used for CSO carbon and a portion of the organic carbon discharged from wastewater treatment plants; labile organic carbon decomposes on the time scale of several weeks to a month or two; refractory organic carbon decomposes on the order of months to a year. Reactive and labile organic carbon decompose primarily in the water column or else rapidly in the sediments. Refractory organic carbon decomposes much more slowly, almost entirely in the sediments.

Reactive particulate organic carbon (RePOC) is assumed to have a very high settling rate that is a function of RePOC itself (representing floculation). The underlying assumption is that at elevated concentrations flocculations occurs, thereby enhancing the settling rate of this form of organic carbon. Equation 1-34 is used to determine the settling rates as a function of REPOC (Figure 1-5 illustrates REPOC

$$v = \min\left[v_{max}, v_{min} + (v_{max} - v_{min})\left(\frac{RePOC}{C_{ref}}\right)^{\beta} \right] \tag{1-34}$$

settling rate as a function of REPOC and the two model coefficients β and C_{ref}). Information from settling column tests can be used to guide the selection of appropriate model coefficients, but it is important to (1) remember that settling column tests are usually conducted under quiescent conditions that may not occur in natural systems and (2) the choice of a maximum settling rate should be made remembering that the maximum rate may influence the integration step-size. For example, assuming a maximum rate of 50 m/day

a water column depth of 1 m and a ten layer sigma-level grid would require a time step of about 2.9 minutes or less to ensure numerical stability.

where

v = settling rate, (m/day)
v_{max} = maximum settling rate, (m/day)
v_{min} = maximum settling rate, (m/day)
RePOC = concentration of reactive (CSO) POC, (mg/L)
C_{ref} = reference concentration of RePOC, (mg/L)
β = power exponent for settling function

The principal sources of organic carbon are anthropogenic inputs and natural runoff, and detrital algal carbon, which is produced as a result of predation. Zooplankton take up and redistribute algal carbon to the organic carbon pools via grazing, assimilation, respiration and excretion. Since zooplankton are not directly included in the model, the redistribution of algal carbon by zooplankton is simulated by empirical distribution coefficients. An additional term, representing the excretion of DOC by phytoplankton during photosynthesis, is included in the model. This algal exudate is very reactive and has a time constant similar to the reactive DOC.

The decomposition of organic carbon is assumed to be temperature and bacterial biomass mediated. Since bacterial biomass is not directly included within the model framework, phytoplankton biomass is used as a surrogate variable. Table 1-5 presents the reaction rate terms and range of coefficients for each of the organic carbon pools considered in the model framework.

TABLE 1-5. ORGANIC CARBON REACTION EQUATIONS
(Numbering scheme refers to the variable list in Section 1.1.2)

Refractory Particulate Organic Carbon (RPOC)

$$S_{18} = f_{RPOC} \cdot k_{grz}\,(T) \cdot P_c - k_{18,20}\,\theta_{18,20}^{\,T-20} \cdot RPOC \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{v_{s18}}{H} \cdot RPOC$$

Labile Particulate Organic Carbon (LPOC)

$$S_{19} = f_{LPOC} \cdot k_{grz}\,(T) \cdot P_c - k_{19,21}\,\theta_{19,21}^{\,T-20} \cdot LPOC \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{v_{s19}}{H} \cdot LPOC$$

Refractory Dissolve Organic Carbon (RDOC)

$$S_{20} = f_{RDOC} \cdot k_{grz}\,(T) \cdot P_c - k_{18,20}\,\theta_{18,20}^{\,T-20} \cdot RPOC \cdot \frac{P_c}{K_{mP_c} + P_c} - k_{20,0}\,\theta_{20,0}^{\,T-20} \cdot RDOC \cdot \frac{P_c}{K_{mP_c} + P_c} \cdot \frac{DO}{K_{DO} + DO}$$

Labile Dissolved Organic Carbon (LDOC)

$$S_{21} = f_{LDOC} \cdot k_{grz}\,(T) \cdot P_c - k_{19,21}\,\theta_{19,21}^{\,T-20} \cdot LPOC \cdot \frac{P_c}{K_{mP_c} + P_c} - k_{21,0}\,\theta_{21,0}^{\,T-20} \cdot LDOC \cdot \frac{P_c}{K_{mP_c} + P_c} \cdot \frac{DO}{K_{DO} + DO} \cdot \frac{LDOC}{K_{mLDOC} + LDOC} - \frac{5}{4} \cdot \frac{12}{14} \cdot k_{15,0}\,\theta_{15,0}^{\,T-20} \cdot NO_2 + NO_3 \cdot \frac{K_{NO_3}}{K_{NO_3} + DO}$$

TABLE 1-5. ORGANIC CARBON REACTION EQUATIONS
(Numbering scheme refers to the variable list in Section 1.1.2)
(Continued)

Algal Exudate Dissolved Organic Carbon (ExDOC)

$$S_{22} = f_{ExPP} \cdot G_P \cdot P_c - k_{22,0}\theta_{22,0}^{T-20} \cdot ExDOC \cdot \frac{P_c}{K_{mP_c} + P_c} \cdot \frac{DO}{K_{DO} + DO} \cdot \frac{ExDOC}{K_{mLDOC} + ExDOC}$$

Reactive Particulate Organic Carbon (RePOC)

$$S_{23} = -k_{23,24}\theta_{23,24}^{T-20} \cdot RePOC \cdot \frac{P_c}{k_{mp_c} + P_c} - \min\left[v_{24\max}, v_{24\min} + (v_{24\max} - v_{24\min})\left(\frac{RePOC}{C_{ref}}\right)^{\beta}\right] \cdot RePOC$$

Reactive Dissolved Organic Carbon (ReDOC)

$$S_{24} = -k_{23,24}\theta_{23,24}^{T-20} \cdot RePOC \cdot \frac{P_c}{k_{mp_c} + P_c} \cdot k_{24,0}\theta_{24,0}^{T-20} \cdot ReDOC \cdot \frac{P_c}{k_{mp_c} + P_c} \cdot \frac{DO}{K_{DO} + DO} \cdot \frac{ReDOC}{K_{mLDOC} + ReDOC}$$

TABLE 1-5. ORGANIC CARBON REACTION EQUATIONS
(Numbering scheme refers to the variable list in Section 1.1.2)

Description	Notation	Value	Units	Murderkill River Model
Phytoplankton Biomass	P_c	-	mgC/L	
Specific Phytoplankton Growth Rate	G_P	Eq. 1-5	day^{-1}	
Segment depth	H	-	m	
Dissolved Oxygen	DO	-	mgO_2/L	
Half Saturation Constant for Phytoplankton Limitation	K_{mPc}	0.05	mgC/L	0.05
Fraction of Grazed Organic Carbon Recycle to:				
the LPOC pool	f_{LPOC}	0.30-0.40		0.40
the RPOC pool	f_{RPOC}	0.10-0.15		0.10
the LDOC pool	f_{LDOC}	0.35-0.45		0.40
the RDOC pool	f_{RDOC}	0.10-0.15		0.10
Note: the sum of $f_{LPOC} + f_{RPOC} + f_{LDOC} + f_{RDOC}$ must equal 1.0				
Fraction of Primary Productivity Going to the Algal Exudate DOC pool	f_{ExPP}	0.10-0.15		0.10
Hydrolysis Rate for RPOC	$k_{18,20}$	0.007-0.01	day^{-1}	0.01
Temperature Coefficient	$\theta_{18,20}$	1.08		1.08
Settling Rate of RPOC	v_{s18}	0.5-1.0	m/day	0.3
Hydrolysis Rate for LPOC	$k_{19,21}$	0.07-0.10	day^{-1}	0.05
Temperature Coefficient	$\theta_{19,21}$	1.08		1.08
Settling Rate of LPOC	v_{s19}	0.5-1.0	m/day	0.3
Oxidation Rate of RDOC	$k_{20,0}$	0.007-0.01	day^{-1}	0.011
Temperature Coefficient	$\theta_{20,0}$	1.08		1.08
Oxidation Rate LDOC	$k_{21,0}$	0.10-0.15	day^{-1}	0.051
Temperature Coefficient	$\theta_{21,0}$	1.08		1.08
Oxidation Rate of ReDOC	$k_{22,0}$	0.25-0.35	day^{-1}	0.05
Temperature Coefficient	$\theta_{22,0}$	1.047		1.047
Oxidation Rate of ExDOC	$k_{23,0}$	0.1	day^{-1}	0.05
Temperature Coefficient	$\theta_{23,0}$	1.08		1.08
Half Saturation for Oxygen Limitation	k_{DO}	0.2	mgO_2/L	0.2
Michaelis Constant for LDOC	K_{mLDOC}	0.1	mgC/L	0.1
Minimum RePOC settling rate	$v_{24\ min}$	0.5	m/day	not used
Enhanced RePOC settling rate (due to floculation)	v_{24max}	25	m/day	not used
Reference (or normalizing term)	C_{Ref}	10	mgC/day	not used
Power function	β	1.2		not used

1.2.3.5 Phosphorus

The eutrophication model includes five principal phosphorus forms: labile and refractory dissolved organic (LDOP and RDOP, respectively), labile and refractory particulate organic (LPOP and RPOP, respectively), and DIP. Inorganic phosphorus is utilized by phytoplankton for growth and phosphorus is returned to the various organic and inorganic forms via respiration and predation. A fraction of the phosphorus released during phytoplankton respiration and predation is in the inorganic form and readily available for uptake by other viable algal cells. The remaining fraction released is in the dissolved and particulate organic forms. The organic phosphorus must undergo a mineralization or bacterial decomposition into inorganic phosphorus before it can be used by phytoplankton. Table 1-6 presents the reaction rate terms for each of the five phosphorus forms.

1.2.3.6 Nitrogen

The kinetic structure for nitrogen is similar to that for the phosphorus system. Table 1-7 summarizes the terms used in the nitrogen system kinetics. During algal respiration and death, a fraction of the cellular nitrogen is returned to the inorganic pool in the form of NH_3. The remaining fraction is recycled to the dissolved and particulate organic nitrogen pools. Organic nitrogen undergoes a bacterial decomposition, the end-product of which is NH_4. Ammonia nitrogen, in the presence of nitrifying bacteria and oxygen, is converted to nitrite nitrogen and subsequently nitrate nitrogen (nitrification). Both ammonia and nitrate are available for uptake and are used in cell growth by phytoplankton; however, for physiological reasons, the preferred form is NH_4. The ammonia preference term takes the following form:

$$\alpha_{NH_4} = NH_4 \cdot \frac{NO_2 + NO_3}{\left(K_{mN} + NH_4\right) \cdot \left(K_{mN} + NO_2 + NO_3\right)} + NH_4 \cdot \frac{K_{mN}}{\left(NH_4 + NO_2 + NO_3\right) \cdot \left(K_{mN} + NO_2 + NO_3\right)} \quad (1\text{-}35)$$

The behavior of this equation for a Michaelis value, K_{mN}, of 10 µgN/L, is illustrated on Figure 1-6. The behavior of Equation 1-35 is most sensitive at low values of ammonia or nitrate. For a given concentration of ammonia, as the available nitrate increases above approximately the Michaelis limitation, the preference for ammonia reaches a plateau. Also, as the concentration of available ammonia increases, the plateau occurs at values closer to unity, that is, total preference for ammonia. The process of nitrification in natural waters is carried out by aerobic autotrophs, *Nitrosomonas* and *Nitrobacter*, in particular. It is a two-step process with *Nitrosomonas* bacteria responsible for the conversion of ammonia to nitrite (NO_2) and *Nitrobacter* responsible for the subsequent conversion of nitrite to nitrate (NO_3). Essential to this reaction process are aerobic conditions. In order to reduce the number of state variables required in the modeling framework, it was decided to incorporate nitrite and nitrate together as a single state variable. Therefore, the process of nitrification is assumed to be approximated by a first-order reaction rate that is a function of the water column dissolved oxygen concentration and ambient temperature.

TABLE 1-6. PHOSPHORUS REACTION RATES
(Numbering scheme refers to the variable list in Section 1.1.2)

Refractory Particulate Organic Phosphorus (RPOP)

$$S_5 = a_{PC} \cdot f_{RPOP} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c - k_{5,7}\,\theta_{5,7}^{T-20} \cdot RPOP \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{v_{s5}}{H} \cdot RPOP$$

Labile Particulate Organic Phosphorus (LPOP)

$$S_6 = a_{PC} \cdot f_{LPOP} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c - k_{6,8}\,\theta_{6,8}^{T-20} \cdot LPOP \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{v_{s6}}{H} \cdot LPOP$$

Refractory Dissolved Organic Phosphorus (RDOP)

$$S_7 = a_{PC} \cdot f_{RDOP} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c + k_{5,7}\,\theta_{5,7}^{T-20} \cdot RPOP \cdot \frac{P_c}{K_{mP_c} + P_c} - k_{7,9}\theta_{7,9}^{T-20} \cdot RDOP \cdot \frac{P_c}{K_{mP_c} + P_c}$$

Labile Dissolved Organic Phosphorus (LDOP)

$$S_8 = a_{PC} \cdot f_{LDOP} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c + k_{6,8}\,\theta_{6,8}^{T-20} \cdot LPOP \cdot \frac{P_c}{K_{mP_c} + P_c} - k_{8,9}\,\theta_{8,9}^{T-20} \cdot LPOP \cdot \frac{P_c}{K_{mP_c} + P_c}$$

TABLE 1-6. PHOSPHORUS REACTION RATES
(Continued)

Dissolved Inorganic Phosphorus (DIP)

$$S_9 = a_{PC} \cdot f_{DIP} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c + \left(k_{7,9}\,\theta_{7,9}^{\,T-20} \cdot RDOP + k_{8,9}\,\theta_{8,9}^{\,T-20} \cdot LDOP\right) \cdot \frac{P_c}{K_{mP_c} + P_c} - a_{PC} \cdot \left(1 - f_{ExPP}\right) \cdot G_P \cdot P_c$$

TABLE 1-6. PHOSPHORUS REACTION RATES
(Continued)

Murderkill River Model

Description	Notation	Value	Units	
Phytoplankton Biomass	P_c	-	mgC/L	
Temperature Corrected Algal Respiration Rate	$k_{PR}(T)$	Eq. 1-11a	day^{-1}	
Temperature Corrected Grazing Rate	$k_{grz}(T)$	Eq. 1-13	day^{-1}	
Specific Phytoplankton Growth Rate	G_P	Eq. 1-5	day^{-1}	
Phosphorus to Carbon Ratio	a_{PC}	Table 1-2	mgP/mgC	
Fraction of Primary Productivity Going to the Algal Exudate DOC pool	f_{ExPP}	0.1		
Fraction of Respired and Grazed Algal Phosphorus Recycled to				
the LPOP pool	f_{LPOP}	0.25-0.35		0.25
the RPOP pool	f_{RPOP}	0.10-0.15		0.10
the LDOP pool	f_{LDOP}	0.10-0.15		0.25
the RDOP pool	f_{RDOP}	0.100.15		0.10
the DIP pool	f_{DIP}	0.20-0.45		0.30
Note: the sum of $f_{LPOP} + f_{RPOP} + f_{LDOP} + f_{RDOP} + f_{DIP}$ must equal 1.0				
RPOP Hydrolysis Rate at 20°C	$k_{5,7}$	0.007-0.01	day^{-1}	0.01
Temperature Coefficient	$\theta_{5,7}$	1.08		1.08
RPOP Settling Rate	v_{s5}	0.5-1.0	m/day	0.3
LPOP Hydrolysis Rate at 20°C	$k_{6,8}$	0.085-0.10	day^{-1}	0.05
Temperature Coefficient	$\theta_{6,8}$	1.08		1.08
LPOP Settling Rate	v_{s6}	0.5-1.0	m/day	0.3
RDOP Mineralization Rate at 20°C	$k_{7,9}$	0.01-0.02	day^{-1}	0.01
Temperature Coefficient	$\theta_{7,9}$	1.08		1.08
LDOP Mineralization Rate at 20°C	$k_{8,9}$	0.1-0.2	day^{-1}	0.05
Temperature Coefficient	$\theta_{8,9}$	1.08		1.08

TABLE 1-7. NITROGEN REACTION RATES
(Numbering scheme refers to the variable list in Section 1.1.2)

Refractory Particulate Organic Nitrogen (RPON)

$$S_{10} = a_{NC} \cdot f_{RPON} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c - k_{10,12}\,\theta_{10,12}^{T-20} \cdot RPON \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{V_{s10}}{H} \cdot RPON$$

Labile Particulate Organic Nitrogen (LPON)

$$S_{11} = a_{NC} \cdot f_{LPON} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c - k_{11,13}\,\theta_{11,13}^{T-20} \cdot LPON \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{V_{s11}}{H} \cdot LPON$$

Refractory Dissolved Organic Nitrogen (RDON)

$$S_{12} = a_{NC} \cdot f_{RDON} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c + k_{10,12}\,\theta_{10,12}^{T-20} \cdot RPON \cdot \frac{P_c}{K_{mP_c} + P_c} - k_{12,14}\,\theta_{12,14}^{T-20} \cdot RDON \cdot \frac{P_c}{K_{mP_c} + P_c}$$

Labile Dissolved Organic Nitrogen (LDON)

$$S_{13} = a_{NC} \cdot f_{LDON} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c + k_{11,13}\,\theta_{11,13}^{T-20} \cdot LPON \cdot \frac{P_c}{K_{mP_c} + P_c} - k_{13,14}\,\theta_{13,14}^{T-20} \cdot LDON \cdot \frac{P_c}{K_{mP_c} + P_c}$$

TABLE 1-7. NITROGEN REACTION RATES
(Continued)

Ammonia Nitrogen (NH_4)

$$S_{14} = a_{NC} \cdot f_{NH_4} \cdot \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c + \left(k_{12,14}\,\theta_{12,14}^{\,T-20} \cdot RDON + k_{13,14}\,\theta_{13,14}^{\,T-20} \cdot LDON\right) \cdot \frac{P_c}{K_{mP_c} + P_c} - a_{NC} \cdot \alpha_{NH_4} \cdot \left(1 - f_{ExPP}\right) \cdot G_P \cdot P_c - k_{14,15}\,\theta_{14,15}^{\,T-20} \cdot NH_4 \cdot \frac{DO}{K_{nitr} + DO}$$

Nitrite + Nitrate Nitrogen (NO_2+ NO_3)

$$S_{15} = k_{14,15}\,\theta_{14,15}^{\,T-20} \cdot NH_4 \cdot \frac{DO}{K_{nitr} + DO} - a_{NC} \cdot \left(1 - \alpha_{NH_4}\right) \cdot \left(1 - f_{ExPP}\right) \cdot G_P \cdot P_c - k_{15,0}\,\theta_{15,0}^{\,T-20} \cdot NO_2 + NO_3 \cdot \frac{K_{NO_3}}{K_{NO_3} + DO}$$

Murderkill River Model

TABLE 1-7. NITROGEN REACTION RATES
(Continued)

Description	Notation	Value	Units	Murderkill River Model
Phytoplankton Biomass	P_c	-	mgC/L	
Temperature Corrected Algal Respiration Rate	$k_{PR}(T)$	cf Eq. 1-11a	day^{-1}	
Temperature Corrected Grazing Rate	$k_{grz}(T)$	cf Eq. 1-13	day^{-1}	
Specific Phytoplankton Growth Rate	G_P	cf Eq. 1-5	day^{-1}	
Nitrogen to Carbon Ration	a_{NC}	cf Table 1-2	mgN/mgC	
Fraction of Primary Productivity Going to the Algal Exudate DOC pool	f_{ExPP}	0.1		
Fraction of Respired and Grazed Algal Nitrogen Recycled to				
The LPON pool	f_{LPON}	0.30-0.35		0.30
the RPON pool	f_{RPON}	0.10-0.15		0.10
the LDON pool	f_{LDON}	0.125-0.15		0.15
the RDON pool	f_{RDON}	0.125-0.20		0.15
the NH_4 pool	f_{NH4}	0.15-0.35		0.30
Note: the sum of $f_{LPON} + f_{RPON} + f_{LDON} + f_{RDON} + f_{NH4}$ must equal 1.0				
RPON Hydrolysis Rate at 20°C	$k_{10,12}$	0.007-0.01	day^{-1}	0.01
Temperature Coefficient	$\theta_{10,12}$	1.08		1.08
RPON Settling Rate	v_{s10}	0.5-1.0	m/day	0.3
LPON Hydrolysis Rate at 20°C	$k_{11,13}$	0.05-0.07	day^{-1}	0.05
Temperature Coefficient	$\theta_{11,13}$	1.08		1.08
LPON Settling Rate	v_{s11}	0.5-1.0	m/day	0.3
RDON Mineralization Rate at 20°C	$k_{12,14}$	0.0080.01	day^{-1}	0.01
Temperature Coefficient	$\theta_{12,14}$	1.08		1.08
LDON Mineralization Rate at 20°C	$k_{13,14}$	0.085-0.10	day^{-1}	0.05
Temperature Coefficient	$\theta_{13,14}$	1.08		1.08
Nitrification Rate at 20°C	$k_{14,15}$	0.05-0.10	day^{-1}	0.05
Temperature Coefficient	$\theta_{14,15}$	1.08		1.08
Half Saturation Constant for Oxygen Limitation	K_{nitr}	1.0	$mg0_2/L$	1.0
Denitrification Rate at 20°C	$K_{15,0}$	0.05-0.4	day^{-1}	0.05
Temperature Coefficient	$\theta_{15,0}$	1.045		1.045
Michaelis Constant for Denitrification	K_{NO_3}	0.1	$mg0_{2/L}$	0.1

Denitrification refers to the reduction of NO_3 to N_2 and other gaseous products such as N_2O and NO. This process is carried out by a large number of heterotrophic, facultative anaerobes. Under normal aerobic conditions found in the water column, these organisms utilize oxygen to oxidize organic material. However, under the anaerobic conditions found in the sediment bed or during extremely low oxygen conditions in the water column, these organisms are able to use NO_3 as the electron acceptor. The process of denitrification is included in the modeling framework simply as a sink of nitrate. This can always occur in the anaerobic sediment layer. In the water column, however, denitrification should only occur under extremely low dissolved oxygen conditions. This is accomplished computationally by modifying the linear first-order denitrification rate by the expression $K_{NO3}/(K_{NO3} + DO)$. This expression is similar to the Michaelis-Menton expression; for concentrations of dissolved oxygen greater than 1 mg/L, the expression reduces denitrification to near zero, whereas for dissolved oxygen levels less than 0.1mg/L, this expression permits denitrification to occur. Table 1-7 presents the state-variable equations for the six nitrogen forms utilized in the model framework.

1.2.3.7 Silica

Two silica state-variables are considered: available (Si) and unavailable or particulate biogenic (SiU). Available silica is dissolved and is utilized by diatoms during growth for their cell structure. Unavailable or particulate biogenic silica is produced from diatom respiration and diatom grazing by zooplankton. Particulate biogenic silica undergoes mineralization to available silica or settles to the sediment from the water column. Table 1-8 presents the state-variable equations for the two silica forms utilized in the model framework.

1.2.3.8 Dissolved Oxygen

A by-product of photosynthetic carbon fixation is the production of dissolved oxygen. The rate of oxygen production and nutrient uptake is proportional to the growth rate of the phytoplankton, since its stoichiometry is fixed. An additional source of oxygen from algal growth occurs when the available ammonia nutrient source is exhausted and the phytoplankton begin to utilize the available nitrate. This additional oxygen source can be seen by comparing equations 1-36a and 1-36b (Morel, 1983).

$$106\ CO_2 + 16\ NH_4^+ + H_2PO_4^- + 106\ H_2O \Rightarrow \text{Protoplasm} + 106\ O_2 + 15H^+ \quad (1\text{-}36a)$$

$$106\ CO_2 + 16\ NO_3^- + H_2PO_4^- + 122\ H_2O + 17H+ \Rightarrow \text{Protoplasm} + 138\ O_2 \quad (1\text{-}36b)$$

The above equations present the stoichiometric description of the photosynthetic process assuming ammonium (Equation 1-36a) or nitrate (Equation 1-36b) as the nitrogen source and assuming algal biomass to have Redfield stoichiometry:

TABLE 1-8. SILICA REACTION EQUATIONS

Biogenic Silica (BSi)

$$S_{16} = \left(k_{PR}(T) + k_{grz}(T)\right) \cdot P_c - k_{16,17}\,\theta_{16,17}^{T-20} \cdot BSi \cdot \frac{P_c}{K_{mP_c} + P_c} - \frac{v_{s16}}{H} \cdot BSi$$

Available Silica (Si)

$$S_{17} = k_{16,17}\,\theta_{16,17}^{T-20} \cdot BSi \cdot \frac{P_c}{K_{mP_c} + P_c} - (1 - f_{ExPP}) \cdot a_{sc} \cdot G_P \cdot P_c$$

Murderkill River Model

Description	Notation	Value	Units	
Phytoplankton Biomass	P_c	—	mgC/L	
Temperature Corrected Algal Respiration Rate	$k_{PR}(T)$	Eq. 1-11a	day^{-1}	
Temperature Corrected Grazing Rate	$k_{grz}(T)$	Eq. 1-13	day^{-1}	
Specific Phytoplankton Growth Rate	G_p	Eq. 1-5	day^{-1}	
Silica to Carbon Ration	a_{sc}	Table 1-2	mgSi/mgC	
Fraction of Primary Productivity Going to the Algal Exudate pool	f_{ExPP}	0.1		
Mineralization Rate of Biogenic Silica	$k_{16,17}$	0.1-0.25	day^{-1}	0.10
Temperature Coefficient	$\theta_{16,17}$	1.08		1.08
Silica Settling Rate	V_{s16}	0.5-1.0	m/day	0.3

$$\text{Biomass} = C_{106}\ H_{263}\ O_{110}\ N_{16}\ P_1 \tag{1-37}$$

Oxygen-deficient or under-saturated waters are replenished via atmospheric reaeration. The reaeration coefficient is a function of the average tidal velocity, wind and temperature, and is computed using Equations 1-38a and 1-38b:

$$k_a\ (20^oC) = \underset{\text{wind}}{K_L / H} \tag{1-38a}$$

$$k_a\ (T) = \underset{\text{temperature}}{k_a\ (20^oC)\theta_a^{T-20}} \tag{1-38b}$$

where

k_a = the surface mass transfer coefficient (m/day),
H = depth (m),
θ_a = temperature coefficient.

Dissolved oxygen saturation is a function of both temperature and salinity and is determined via Equation 1-39 (Standard Methods, 1992):

$$\begin{aligned} DO_{sat} = \exp\ [&-139.34411 + 1.575701 \cdot 10^5 / T \\ &-6.642308 \cdot 10^7 / T^2 + 1.243800 \cdot 10^{10} / T^3 \\ &-8.621949 \cdot 10^{11} / T^4 - S(1.7674 \cdot 10^{-2} \\ &-10.754 / T + 2140.7 / T^2)] \end{aligned} \tag{1-39}$$

where

S = salinity (psu),
T = temperature (°K).

Dissolved oxygen is diminished in the water column as a result of algal respiration, which is the reverse process of photosynthesis; as a result of nitrification:

$$NH_4^+ + 2O_2 \Rightarrow NO_3^- + H_2O + 2H^+ \tag{1-40}$$

as a result of the oxidation of carbonaceous material (including detrital phytoplankton):

$$CH_2O + O_2 \Rightarrow CO_2 + H_2O \quad (1\text{-}41)$$

and, if dissolved oxygen concentrations are sufficiently low, as a result of denitrification:

$$5CH_2O + 4NO_3^- + \Rightarrow 5CO_2 + 2N_2 + 7H_2O \quad (1\text{-}42)$$

Table 1-9 presents a summary of the dissolved oxygen mass balance equation and associated coefficients incorporated in the integrated eutrophication model.

TABLE 1-9. DISSOLVED OXYGEN AND O_2^* REACTION RATES

Sulfide Oxygen Equivalents (O_2^*)

$$S_{24} = K_{O_2^*}\,\theta_{O_2^*}^{T-20} \cdot O_2^* \cdot \frac{P_c}{K_{mP_c} + P_c} \cdot \frac{DO}{K_{DO_{O_2^*}} + DO}$$

Dissolved Oxygen (DO)

$$\begin{aligned} S_{25} = {} & a_{OC} \cdot \alpha_{NH_4} \cdot G_P \cdot P_c + \left(a_{NO_3} c\right) \cdot \left(1-\alpha_{NH_4}\right) \cdot G_P \cdot P_c \\ & + k_a \theta_a^{T-20} \cdot \left(DO_{sat} - DO\right) - a_{OC} \cdot k_{PR}\,(T) \cdot P_c \\ & - 2 \cdot a_{ON} \cdot k_{14,15} \theta_{14,15}^{T-20} \cdot NH_4 \cdot \frac{DO}{K_{nitr} + DO} \\ & - a_{OC} \cdot \left[k_{20,0}\,\theta_{20,0}^{T-20} \cdot RDOC + k_{21,0}\,\theta_{21,0}^{T-20} \cdot LDOC \cdot \frac{LDOC}{K_{m_{LDOC}} + LDOC} \right. \\ & + k_{22,0}\,\theta_{22,0}^{T-20} \cdot Re\,DOC \cdot \frac{Re\,DOC}{K_{mLDOC} + Re\,DOC} \\ & \left. + k_{23,0}\,\theta_{23,0}^{T-20} \cdot ExDOC \cdot \frac{ExDOC}{K_{mLDOC} + ExDOC} \right] \cdot \frac{P_c}{K_{mPc} + P_c} \cdot \frac{DO}{K_{DO} + DO} \\ & - k_{o_2^*}\,\theta_{o_2^*}^{T-20} \cdot O_2^* \cdot \frac{P_c}{K_{mPc} + P_c} \cdot \frac{DO}{K_{DO_{O_2^*}} + DO} \end{aligned}$$

TABLE 1-9. DISSOLVED OXYGEN AND O_2^* REACTION RATES
(continued)

Murderkill River Model

Description	Notation	Value	Units	
		Rate Constants		
Oxygen to Carbon Ratio	a_{OC}	32/12	$mgO_2/mg\ C$	3.5
Oxygen to Nitrogen Ratio	a_{ON}	32/14	$mgO_2/mg\ N$	2.29
Oxygen to Carbon Ratio for Nitrate Uptake	α_{NO_3C}	$\frac{48}{14} a_{NC}$	$mgO_2/mg\ C$	3.43
Reaeration Rate at 20°C	k_a	Eq. 1.19a	day^{-1}	f(wind,vel)
Temperature Coefficient	θ_a	1.024	none	1.024
Oxygen Transfer Coefficient	k_L	0.75-1.8	m/day	min 0.3
Dissolved Oxygen Saturation	DO_{sat}	Eq. 1.20	mgO_2/L	
Oxidation Rates and Temperature Coefficients				
for RDOC	$k_{20,0}$ $\theta_{20,0}$	0.008-0.01 1.08	day^{-1}	
for LDOC	$k_{21,0}$ $\theta_{21,0}$	0.10-0.15 1.047	day^{-1}	
for ReDOC	$k_{22,0}$ $\theta_{22,0}$	0.25-0.3 1.047	day^{-1}	
for ExDOC	$k_{23,0}$ $\theta_{23,0}$	0.1-0.125 1.08	day^{-1}	
Oxidation Rate of Dissolved Sulfide	$k_{o_2^*}$	0.15-0.5	day^{-1}	0.15
Temperature Coefficient	$\theta_{o_2^*}$	1.08		1.08
Half Saturation for Oxygen Limitation	$k_{DO_{o_2^*}}$	0.2	mgO_2/L	0.1

1.2.4 Specification of Input Variables Associated with the Eutrophication Model

As described earlier, the user has the choice of two algal growth formulation - the standard formulation and the Laws-Chalup formulation. The user can also select whether to simulate one, two, or three algal groups. In addition, the user can select from various options to specify the reaeration coefficient and the extinction coefficient. These selections are provided for via the first three constants specified in Card Group L (more specifically in L10). These constants are described below.

Constant Number	Name	Description
1	AGOPT	algal growth model option = 0, use standard or traditional algal growth kinetics = 1, use Laws-Chalup formulation
2	ACTALG	number of algal groups to simulate = 1, just one group (state-variable #2) will be simulated = 2, two groups will be simulated (using state-variables #2 and #3) = 3, three algal groups will be simulated (using state-variables #2 through #4)
3	KAOPT	reaeration formulation option = 0, use spatially constant k_L ($k_a = k_L$/depth) = 1, use spatially variable k_L = 2, use velocity shear and oxygen diffusivity = 3, use wind shear formulation
4	KEOPT	extinction coefficient option = 0, k_e is a constant (spatially and temporally invariant = 1, k_e is a spatially variable but constant in time(using 2-d parameter array) = 2, k_e is spatially invariant but varies in time (using time-variable function) = 3, k_e is spatially variable and can vary in time, (using 2-d parameter array and one time-variable function) = 4, k_e is spatially and temporally variable (requires separate input file)

TABLE 1-10. KINETIC CONSTANTS USED FOR STANDARD EUTROPHICATION ALGAL GROWTH MODEL

If <AGOPT> = 0 then the following constants (9 through 99) are used by the eutrophication model and must be specified by the user. If the user is simulating only one phytoplankton group then constants 41-99 can be ignored; if the user is simulating two group then constants 73-99 can be ignored.

Number	Name	Description	Units
9	TOPT1	optimal growth temperature for algal group #1	deg C
10	K1BETA1	temperature correction effect on growth rate below <TOPT1>	$(\text{deg C})^{-2}$
11	K1BETA2	temperature correction effect on growth rate above <TOPT1>	$(\text{deg C})^{-2}$
12	K1C	saturated phytoplankton growth rate (at temperature = <TOPT1>)	/day
13	K1T	temperature coefficient	
14	IS1	saturating algal light intensity	ly/day
15	KMN1	half saturation constant for nitrogen	mg N/L
16	KMP1	half saturation constant for phosphorous	mg P/L
17	KMS1	half saturation constant for silica	mg Si/L
18	K1RB	basal/resting respiration rate -or- endogenous respiration rate at 20 deg C	/day
19	K1RT	temperature coefficient	
20	K1RG	growth-rate-dependent respiration coefficient	
21	K1GRZC	death rate due to grazing	/day
22	K1GRZT	temperature coefficient	
23	CCHL1	carbon to chlorophyll ratio	mg C/mg Chla
24	CRBP11	carbon to phosphorus ratio - non-P limited	mg C/mg P
25	CRBP12	carbon to phosphorus ratio - P limited	mg C/mg P
26	CRBP13	coefficient determining range of P limitation	L/mg P
27	CRBN11	carbon to nitrogen ratio - non-N limited	mg C/mg N
28	CRBN12	carbon to nitrogen ratio - N limited	mg C/mg N
29	CRBN13	coefficient determining range of N limitation	L/mg N
30	CRBS11	carbon to silica ratio - non-Si limited	mg C/mg Si
31	CRBS12	carbon to silica ratio - Si limited	mg C/mg Si
32	CRBS13	coefficient determining range of Si limitation	L/mg Si
33	XKC1	chlorophyll self-shading extinction coefficient	m^2/mg Chla
34	VSBAS1	base algal settling rate	m/day
35	VSNTR1	nutrient stressed algal settling rate	m/day

TABLE 1-10. KINETIC CONSTANTS USED FOR STANDARD EUTROPHICATION ALGAL GROWTH MODEL (Continued)

41	TOPT2	optimal growth temperature for algal group #2	deg C
42	K2BETA1	temperature correction effect on growth rate below <TOPT2>	$(\text{deg C})^{-2}$
43	K2BETA2	temperature correction effect on growth rate above <TOPT2>	$(\text{deg C})^{-2}$
44	K2C	saturated phytoplankton growth rate (at temperature = <TOPT2>)	/day
45	K2T	temperature coefficient	
46	IS2	saturating algal light intensity	ly/day
47	KMN2	half saturation constant for nitrogen	mg N/L
48	KMP2	half saturation constant for phosphorous	mg P/L
49	KMS2	half saturation constant for silica	mg Si/L
50	K2RB	basal/resting respiration rate -or- endogenous respiration rate at 20 deg C	/day /day
51	K2RT	temperature coefficient	
52	K2RG	growth-rate-dependent respiration coefficient	
53	K2GRZC	death rate due to grazing	/day
54	K2GRZT	temperature coefficient	
55	CCHL2	carbon to chlorophyll ratio	mg C/mg Chla
56	CRBP21	carbon to phosphorus ratio - non-P limited	mg C/mg P
57	CRBP22	carbon to phosphorus ratio - P limited	mg C/mg P
58	CRBP23	coefficient determining range of P limitation	L/mg P
59	CRBN21	carbon to nitrogen ratio - non-N limited	mg C/mg N
60	CRBN22	carbon to nitrogen ratio - N limited	mg C/mg N
61	CRBN23	coefficient determining range of N limitation	L/mg N
62	CRBS21	carbon to silica ratio - non-Si limited	mg C/mg Si
63	CRBS22	carbon to silica ratio - Si limited	mg C/mg Si
64	CRBS23	coefficient determining range of Si limitation	L/mg Si
65	XKC2	chlorophyll self-shading extinction coefficient	m^2/mg Chla
66	VSBAS2	base algal settling rate	m/day
67	VSNTR2	nutrient stressed algal settling rate	m/day

TABLE 1-10. KINETIC CONSTANTS USED FOR STANDARD EUTROPHICATION ALGAL GROWTH MODEL (Continued)

73	TOPT3	optimal growth temperature for algal group #3	deg C
74	K3BETA1	temperature correction effect on growth rate below <TOPT1>	$(\text{deg C})^{-2}$
75	K3BETA2	temperature correction effect on growth rate above <TOPT1>	$(\text{deg C})^{-2}$
76	K3C	saturated phytoplankton growth rate (at temperature = <TOPT1>)	/day
77	K3T	temperature coefficient	
78	IS3	saturating algal light intensity	ly/day
79	KMN3	half saturation constant for nitrogen	mg N/L
80	KMP3	half saturation constant for phosphorous	mg P/L
81	KMS3	half saturation constant for silica	mg Si/L
82	K1RB	basal/resting respiration rate -or- endogenous respiration rate at 20 deg C	/day /day
83	K3RT	temperature coefficient	
84	K3RG	growth-rate-dependent respiration coefficient	
85	K3GRZC	death rate due to grazing	/day
86	K3GRZT	temperature coefficient	
87	CCHL3	carbon to chlorophyll ratio	mg C/mg Chla
88	CRBP31	carbon to phosphorus ratio - non-P limited	mg C/mg P
89	CRBP32	carbon to phosphorus ratio - P limited	mg C/mg P
90	CRBP33	coefficient determining range of P limitation	L/mg P
91	CRBN31	carbon to nitrogen ratio - non-N limited	mg C/mg N
92	CRBN32	carbon to nitrogen ratio - N limited	mg C/mg N
93	CRBN33	coefficient determining range of N limitation	L/mg N
94	CRBS31	carbon to silica ratio - non-Si limited	mg C/mg Si
95	CRBS32	carbon to silica ratio - Si limited	mg C/mg Si
96	CRBS33	coefficient determining range of Si limitation	L/mg Si
97	XKC3	chlorophyll self-shading extinction coefficient	m^2/mg Chla
98	VSBAS3	base algal settling rate	m/day
99	VSNTR3	nutrient stressed algal settling rate	m/day
105	KMPHYT	half saturation constant for phytoplankton	mg C/L

TABLE 1-11. KINETIC CONSTANTS USED FOR LAWS-CHALUP EUTROPHICATION ALGAL GROWTH MODEL

If <AGOPT> = 1 then the following constants (6 through 95) are used by the eutrophication model and must be specified by the user. If the user is simulating only one phytoplankton group, then constants 41-95 can be ignored; if the user is simulating only two groups, then constants 73-95 can be ignored.

9	TOPT1	optimal growth temperature for algal group #1	deg C
10	K1BETA1	temperature correction effect on growth rate below <TOPT1>	$(\text{deg C})^{-2}$
11	K1BETA2	temperature correction effect on growth rate above <TOPT1>	$(\text{deg C})^{-2}$
12	GPRE1	gross photosynthetic rate per unit cell (associated with photosynthetic dark reactions)	/day
13	GPR01	gross photosynthetic rate per unit cell per unit light intensity under nutrient-saturated conditions and zero irradiance	m^2/mol quanta
14	IS1	saturating algal light intensity	ly/day
15	KMN1	half saturation constant for nitrogen	mg N/L
16	KMP1	half saturation constant for phosphorous	mg P/L
17	KMS1	half saturation constant for silica	mg Si/L
18	K1RB	basal or resting respiration rate	/day
19	K1RT	temperature coefficient for basal/endogenous respiration	
20	K1RG	growth-rate-dependent respiration coefficient	
21	K1GRZC	death rate due to grazing	/day
22	K1GRZT	temperature coefficient	
23	FSC1	fraction of C allocated to structural purposes	
24	WCCHL1	carbon to chlorophyll ratio	mg C/mg Chla
25	WCP1	carbon to phosphorus ratio - non-P limited	mg C/mg P
26	WCN1	carbon to nitrogen ratio - non-N limited	mg C/mg N
27	WCS1	carbon to silica ratio - non-Si limited	mg C/mg Si
28	QF1	quotient of nutrient-limited nutrient:C ratios at relative growth rates of 0 and 1	
29	XKC1	chlorophyll self-shading extinction coefficient	m^2/mg Chla
30	VSBAS1	base algal settling rate	m/day
31	VSNTR1	nutrient stressed algal settling rate	m/day

TABLE 1-11. KINETIC CONSTANTS USED FOR LAWS-CHALUP EUTROPHICATION ALGAL GROWTH MODEL (Continued)

41	TOPT2	optimal growth temperature for algal group #2	deg C
42	K2BETA1	temperature correction effect on growth rate below <TOPT2>	$(\text{deg C})^{-2}$
43	K2BETA2	temperature correction effect on growth rate above <TOPT2>	$(\text{deg C})^{-2}$
44	GPRE2	gross photosynthetic rate per unit cell (associated with photosynthetic dark reactions)	/day
45	GPR02	gross photosynthetic rate per unit cell per unit light intensity under nutrient-saturated conditions and zero irradiance	m^2/mol quanta
46	IS2	saturating algal light intensity	ly/day
47	KMN2	half saturation constant for nitrogen	mg N/L
48	KMP2	half saturation constant for phosphorous	mg P/L
49	KMS2	half saturation constant for silica	mg Si/L
50	K2RB	basal or resting respiration rate	/day
51	K2RT	temperature coefficient for basal/endogenous respiration	
52	K2RG	growth-rate-dependent respiration coefficient	
53	K2GRZC	death rate due to grazing	/day
54	K2GRZT	temperature coefficient	
55	FSC2	fraction of C allocated to structural purposes	
56	WCCHL2	carbon to chlorophyll ratio	mg C/mg Chla
57	WCP2	carbon to phosphorus ratio - non-P limited	mg C/mg P
58	WCN2	carbon to nitrogen ratio - non-N limited	mg C/mg N
59	WCS2	carbon to silica ratio - non-Si limited	mg C/mg Si
60	QF2	quotient of nutrient-limited nutrient: C ratios at relative growth rates of 0 and 1	
61	XKC2	chlorophyll self-shading extinction coefficient	m^2/mg Chla
62	VSBAS2	base algal settling rate	m/day
63	VSNTR2	nutrient stressed algal settling rate	m/day

TABLE 1-11. KINETIC CONSTANTS USED FOR LAWS-CHALUP EUTROPHICATION ALGAL GROWTH MODEL (Continued)

73	TOPT3	optimal growth temperature for algal group #3	deg C
74	K3BETA1	temperature correction effect on growth rate below <TOPT1>	$(\text{deg C})^{-2}$
75	K3BETA2	temperature correction effect on growth rate above <TOPT1>	$(\text{deg C})^{-2}$
76	GPRE3	gross photosynthetic rate per unit cell (associated with photosynthetic dark reactions)	/day
77	GPR03	gross photosynthetic rate per unit cell per unit light intensity under nutrient-saturated conditions and zero irradiance	m^2/mol quanta
78	IS3	saturating algal light intensity	ly/day
79	KMN3	half saturation constant for nitrogen	mg N/L
80	KMP3	half saturation constant for phosphorous	mg P/L
81	KMS3	half saturation constant for silica	mg Si/L
82	K3RB	basal or resting respiration rate	/day
83	K3RT	temperature coefficient for basal/endogenous	
84	K3RG	growth-rate-dependent respiration coefficient respiration	
85	K3GRZC	death rate due to grazing	/day
86	K3GRZT	temperature coefficient	
87	FSC3	fraction of C allocated to structural purposes	
88	WCCHL3	carbon to chlorophyll ratio	mg C/mg Chla
89	WCP3	carbon to phosphorus ratio - non-P limited	mg C/mg P
90	WCN3	carbon to nitrogen ratio - non-N limited	mg C/mg N
91	WCS3	carbon to silica ratio - non-Si limited	mg C/mg Si
92	QF3	quotient of nutrient-limited nutrient: C ratios at relative growth rates of 0 and 1	
93	XKC3	chlorophyll self-shading extinction coefficient	m^2/mg Chla
94	VSBAS3	base algal settling rate	m/day
95	VSNWTR3	nutrient stressed algal settling rate	m/day
105	KMPHYT	half saturation constant for phytoplankton	mg C/L

TABLE 1-12. REMAINING KINETIC CONSTANTS USED FOR INTEGRATED EUTROPHICATION MODEL

		Recycle Fractions - Fraction of Grayed/Respired Algal Biomass Going to....	
106	FRPOP	refractory particulate organic phosphorous	
107	FLPOP	labile particulate organic phosphorous	
108	FRDOP	refractory dissolved organic phosphorous	
109	FLDOP	labile dissolved organic phosphorous	
110	FPO4	dissolved inorganic phosphorous	
111	FRPON	refractory particulate organic nitrogen	
112	FLPON	labile particulate organic nitrogen	
113	FRDON	refractory dissolved organic nitrogen	
114	FLDON	labile dissolved organic nitrogen	
115	FNH4	ammonia	
116	FRPOC	refractory particulate organic carbon	
117	FLPOC	labile particulate organic carbon	
118	FRDOC	refractory dissolved organic carbon	
119	FLDOC	labile dissolved organic carbon	
		Phosphorus Hydrolysis/Mineralization Rates at 20 deg C	
120	K57C	hydrolysis rate of RPOP to RDOP	/day
121	K57T	temperature coefficient	
122	K68C	hydrolysis rate of LPOP to LDOP	/day
123	K68T	temperature coefficient	
124	K79C	mineralization rate of RDOP to PO4	/day
125	K79T	temperature coefficient	
126	K89C	mineralization rate of LDOP to PO4	/day
127	K89T	temperature coefficient	
		Nitrogen Hydrolysis/Mineralization Rates at 20 deg C	
128	K1012C	hydrolysis rate of RPON to RDON	/day
129	K1012T	temperature coefficient	
130	K1113C	hydrolysis rate of LPON to LDON	/day
131	K1113T	temperature coefficient	
132	K1214C	mineralization rate of RDON to NH4	/day
133	K1214T	temperature coefficient	
134	K1314C	mineralization rate of LDON to NH4	/day
135	K1314T	temperature coefficient	

TABLE 1-12. REMAINING KINETIC CONSTANTS USED FOR INTEGRATED EUTROPHICATION MODEL (Continued)

		Nitrification/Denitification Rates	
136	K1415C	nitrification rate at 20 deg C	/day
137	K1415T	temperature coefficient	
138	KNIT	half saturation constant for nitrification oxygen limitation	mg O2/L
139	K150C	denitrification rate at 20 deg C	/day
140	K150T	temperature coefficient	
141	KNO3	Michaelis constant for denitrification oxygen limitation	mg O2/L
		Silica Mineralization Rates at 20 deg C	
142	K1617C	mineralization rate of biogenic Si to available dissolved Si	/day
143	K1617T	temperature coefficient	
		Carbon Hydrolysis/Oxidation Rates at 20 deg C	
144	K1820C	hydrolysis rate of RPOC to RDOC	/day
145	K1820T	temperature coefficient	
146	K1921C	hydrolysis rate of LPOC to LDOC	/day
147	K1921T	temperature coefficient	
148	K200C	oxidation rate of RDOC	/day
149	K200T	temperature coefficient	
150	K210C	oxidation rate of LDOC	/day
151	K210T	temperature coefficient	
152	KMLDOC	Michaelis constant for LDOC	mg C/L
153	KDOC	half saturation constant for organic carbon	mg O2/L
154	K220C	algal exudate DOC oxidation rate	/day
155	K220T	temperature coefficient	
156	FLOCEX	fraction of primary productivity going to labile organic carbon via exudation	
157	K2324C	hydrolysis rate of REPOC to REDOC	/day
158	K2324T	temperature coefficient	
159	K240C	reactive DOC oxidation rate	/day
160	K240T	temperature coefficient	
161	CTOPCSO	carbon to phosphorus ratio of CSO solids	mg C/mg P
162	CTONCSO	carbon to nitrogen ratio of CSO solids	mg C/mg N
163	K250C	oxidation rate for aqueous sod	/day
164	K250T	temperature coefficient	

TABLE 1-12. REMAINING KINETIC CONSTANTS USED FOR INTEGRATED EUTROPHICATION MODEL (Continued)

165	KO2EQ	half saturation constant for O_2^*	mg O_2/L
166	KLMIN	if <KAOPT> = 0, then $K_{lmin} = K_l$ if <KAOPT> > 0, then K_{lmin} = minimum value for K_l	m/day
167	DIFUS	diffusivity of oxygen across the air-water interface	m^2/day
168	KAT	temperature correction coefficient for atmospheric reaeration	
169	VSBAST	temperature correction	
170	VSPOM	particulate organic matter settling rate	m/day
171	VSPMT	temperature correction	
172	VSSEDT	temperature correction for deposition to sediment	
173	BVCSO	power coefficient for CSO solid settling rate (>=1)	unitless
174	CRCSO	critical REPOC concentration for CSO settling function	mg C/L
175	VMINCSO	minimum settling rate for CSO solids Vcso =min (VMAXCSO + VMINCSO + (VMAXCSO - VMINCSO) * (REPOC/CRCSO)**BVCSO)	m/day
176	VMAXCSO	maximum settling rate for CSO solids	m/day
177	KADPO4	partition coefficient for sorbed phosphorus	L/mg ss
178	KADSI	partition coefficient for sorbed silica	L/mg ss
179	VSPIM	settling rate for phosphorus/silica sorbed to suspended solids	m/day
180	KECONST	base (chl-a corrected) extinction coefficient (used when <KEOPT> = 0,2)	/m

1.2.4.1 Parameters, Constants, and Time Functions

The parameters, constants, and time functions required by the kinetics of this model are specified according to the formatting described for input Group L in the RCA Users Guide. Table 1-13 lists the required two dimensional segment parameters. No three dimensional parameters are included in the kinetic routine. Required time variable functions are described in Table 1-14.

TABLE 1-13. 2-D PARAMETERS

Number	Name	Description	Units
1	KL	transfer coefficient for reaeration	m/day
2	VSNET1	settling efficiency from water column to the bed for algal group number 1 (the winter diatom group)	
3	VSNET2	settling efficiency from water column to the bed for algal group number 2 (the summer mixed assemblage)	m/day
4	VSNET3	settling efficiency from water column to bed for algal group number 3	m/day
5	VSNET4	settling efficiency from water column to the bed for non-living particulate organic matter (POM)	m/day
6	KEBS	base extinction coefficient (when KEOPT - 1 or 3)	m^{-1}

Note: by settling efficiency, it is meant the "stickiness" of a particle settling from the water column to the sediment bed; range 0 to 1. If VSNET = 1, all of the particles settling from the water column to the bed, stick to the bed and become incorporated in the sediment. If VSNET = 0.5, only half of the particles settling from the water column to the bed become incorporated in the sediment; the remainder are assumed to become "resuspended" and may be transported elsewhere. If VSNET = 0, none of the particles settle to the bed, i.e., no deposition in this segment.

TABLE 1-14. TIME-VARIABLE FUNCTIONS

Number	Name	Description	Units
1	ITOTSF	total daily solar radiation	ly/day
2	F	fraction of daylight	day
3	WIND	wind speed	m/sec
4	KETVF	extinction coefficient (when KEOPT = 2 or 3)	m^{-1}

Table 1-15 presents a sample input deck for the standard eutrophication model coefficient set, which includes one kinetic subroutine specific file, i.e., the sediment nutrient flux subroutine input data set.

TABLE 1-15. SAMPLE EUTROPHICATION INPUT DATASET

```
C N2DPARAM
         6
C    Scale1     Scale2     Scale3     Scale4
     0.3048        1.0        1.0        1.0
kL
     0.0000     0.0000     0.0000
     0.0000     0.7870     0.0000
     0.0000     0.0000     0.0000
Vsnet1 - algal group 1
     0.0000     0.0000     0.0000
     0.0000     1.0000     0.0000
     0.0000     0.0000     0.0000
Vsnet2 - algal group 2
     0.0000     0.0000     0.0000
     0.0000     1.0000     0.0000
     0.0000     0.0000     0.0000
Vsnet3 - algal group 3
     0.0000     0.0000     0.0000
     0.0000     1.0000     0.0000
     0.0000     0.0000     0.0000
Vsnet4 - pom
     0.0000     0.0000     0.0000
     0.0000     1.0000     0.0000
     0.0000     0.0000     0.0000
KEbs
     0.0000     0.0000     0.0000
     0.0000     0.0000     0.0000
     0.0000     0.0000     0.0000
C N3DPARAM
    1                                  number of 3D parameters
C    SCALE1
   1.0E-20
SS (mg/L)
       0.01       0.01       0.01
       0.01       0.01       0.01
       0.01       0.01       0.01           Layer #1
       0.01       0.01       0.01
       0.01       0.01       0.01
       0.01       0.01       0.01           Layer #2
C     NCONS
        180                                    number of constants
      AGOPT     ACTALG      KAOPT      KEOPT     Unused     Unused     Unused     Unused
         0.         2.         1.         2.
      TOPT1    K1BETA1    K2BETA2       K1C        K1T        IS1       KMN1       KMP1
       3.50       .004       .006      2.500      1.068    150.000      0.010      0.001
       KMS1       K1RB       K1RT       K1RG      K1GZC      K1GZT      CCHL1      CPR11
      0.020      0.075      1.047        0.0      0.100       1.10       30.0       40.0
      CPR12      CPR13      CNR11      CNR12      CNR13      CSR11      CSR12      CSR13
        0.0        0.0      5.670        0.0        0.0        5.0       10.0        0.0
       XKC1     VSBAS1     VSNTR1    Unused     Unused     Unused     Unused     Unused
      0.017        0.2        0.5
      TOPT2    K2BETA1    K2BETA2       K2C        K2T        IS2       KMN2       KMP2
         22.       .004       .006      2.400      1.068      350.      0.010      0.001
       KMS2       K2RB       K2RT       K2RG      K2GZC      K2GRT      CCHL2      CPR21
      0.002      0.075      1.047        0.0      0.120      1.100       80.0       40.0
      CPR22      CPR23      CNR21      CNR22      CNR23      CSR21      CSR22      CSR23
        0.0        0.0      5.670        0.0        0.0        8.0        0.0        0.0
       XKC2     VSBAS2     VSNTR2    Unused     Unused     Unused     Unused     Unused
      0.017        0.5        0.2
      TOPT3    K3BETA1    K3BETA2       K3C        K3T        IS3       KMN3       KMP3
         0.         0.         0.         0.         0.         0.         0.         0.
       KMS3       K3RB       K3RT       K3RG      K3GZC      K3GRT      CCHL3      CPR31
         0.         0.         0.         0.         0.         0.         0.         0.
      CPR32      CPR33      CNR31      CNR32      CNR33      CSR31      CSR32      CSR33
```

TABLE 1-15. SAMPLE EUTROPHICATION INPUT DATASET (Cont.)

```
        0.        0.        0.        0.        0.        0.        0.        0.
      XKC3    VSBAS3    VSNTR3    Unused    Unused    Unused    Unused    Unused
        0.        0.        0.
     KMPHY     FRPOP     FLPOP     FRDOP     FLDOP      FPO4     FRPON     FLPON
     0.050     0.100     0.250     0.100     0.100     0.450     0.001     0.399
     FRDON     FLDON      FNH4     FRPOC     FLPOC     FRDOC     FLDOC      K57C
     0.125     0.125     0.350     0.001     0.449     0.100     0.450     0.010
      K57T      K68C      K68T      K79C      K79T      K89C      K89T    K1012C
     1.080     0.070     1.080     0.020     1.080     0.090     1.080     0.010
    K1012T    K1113C    K1113T    K1214C    K1214T    K1314C    K1314T    K1415C
     1.080     0.050     1.080     0.010     1.080     0.075     1.080     0.040
    K1415T      KNIT     K150C     K150T      KNO3    K1617C    K1617T    K1820C
     1.040     1.500     0.050     1.045     0.010      0.10     1.080     0.010
    K1820T    K1921C    K1921T    K200C     K200T     K210C     K210T    KMLDOC
     1.080     0.070     1.080     0.010     1.080     0.150     1.047     0.100
      KDOC     K220C     K220T    FLOCEX    K2324C    K2324T     K24OC     K24OT
     0.200     0.120     1.047       0.0      0.35     1.047     0.100     1.080
   CTOPCSO   CTONCSO     K25OC     K25OT     KO2EQ     KLMIN     DIFUS       KAT
        35.       6.0     0.150     1.080     0.100       2.0      0.00     1.024
    VSBAST     VSPOM     VSPMT    VSSEDT     BVCSO     CRCSO    KADPO4    KADSI
     1.000     0.750      1.00       1.0       2.0       10.       6.0       6.0
     VSPIM   KECONST
       0.0       0.0
C    NOTVF   TVPWLOPT
         4         1                    number of time functions
C    PNAME     NOBRK   TWARPTVF
      ITOT        13      DAYS          TOTAL DAILY RADIATION
      118.        0.      168.        11.       218.       59.       318.       90.
      418.      120.      468.       151.       518.      181.       468.      212.
      418.      243.      318.       273.       218.      304.       168.      335.
      118.      365.
C    PNAME     NOBRK   TWARPTVF
     F DAY        13      DAYS          FRACTION OF DAYLIGHT
      0.37        0.      0.42        31.       0.46       59.       0.52       90.
      0.58      120.      0.61       151.       0.63      181.       0.59      212.
      0.54      243.      0.49       273.       0.43      304.       0.40      335.
      0.37      365.
C    PNAME     NOBRK   TWARPTVF
      Wind         2      DAYS          Wind Speed (m/sec)
      000.        0.      000.      9999.
C    PNAME     NOBRK   TWARPTVF
        KE        13      DAYS          Extinction coefficient (/m)
      0.70        0.      0.65        31.       0.60       59.       0.55       90.
      0.73      120.      0.96       151.       1.12      181.       0.74      212.
      0.57      243.      0.57       273.       0.51      304.       0.63      335.
      0.67      365.
C NOKINFIL                          Number of kinetic subroutine specific files
         1
sed.inp
```

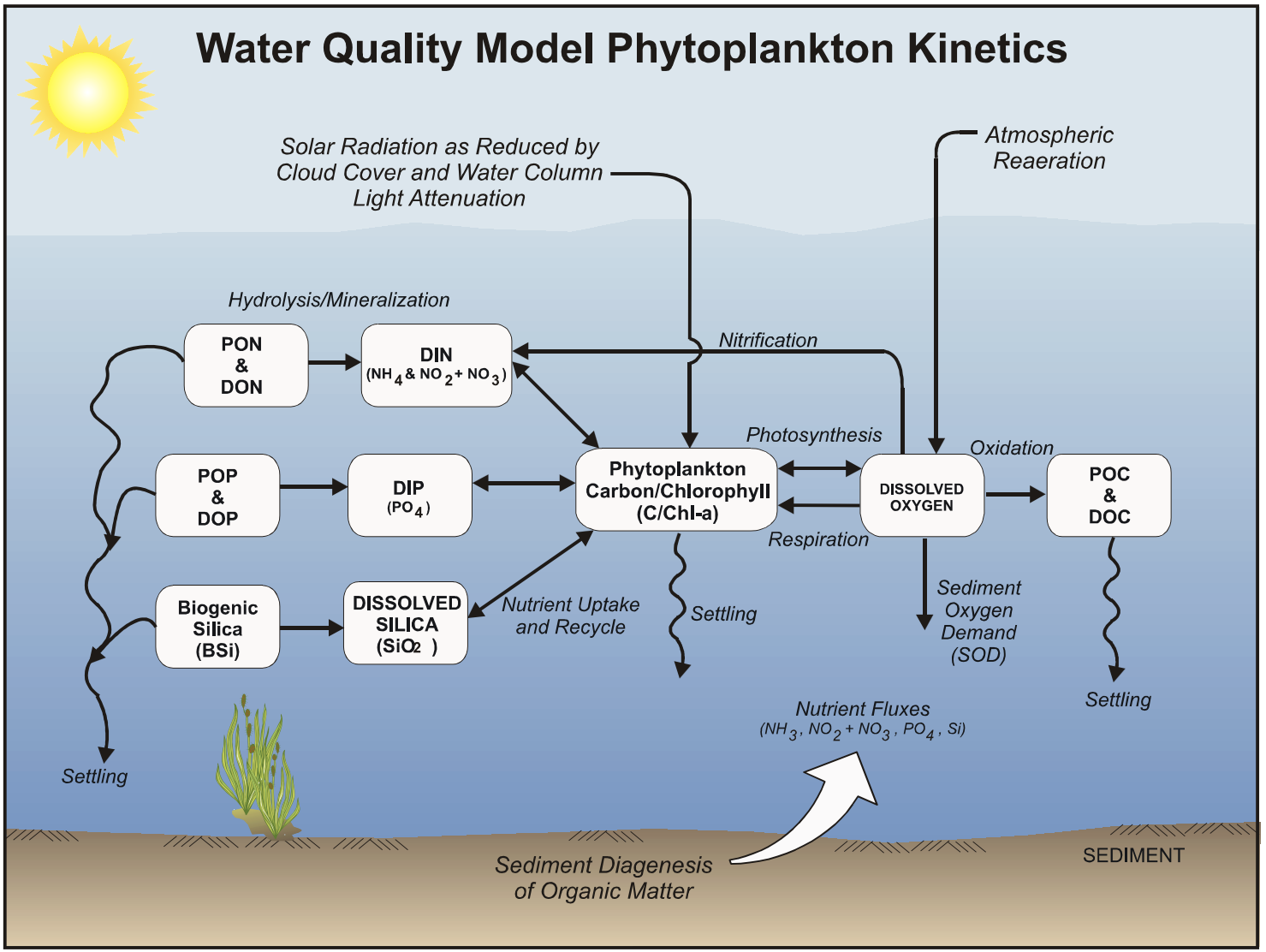


Figure 1-1. Principal Kinetic Interactions for Nutrient Cycles and Dissolved Oxygen

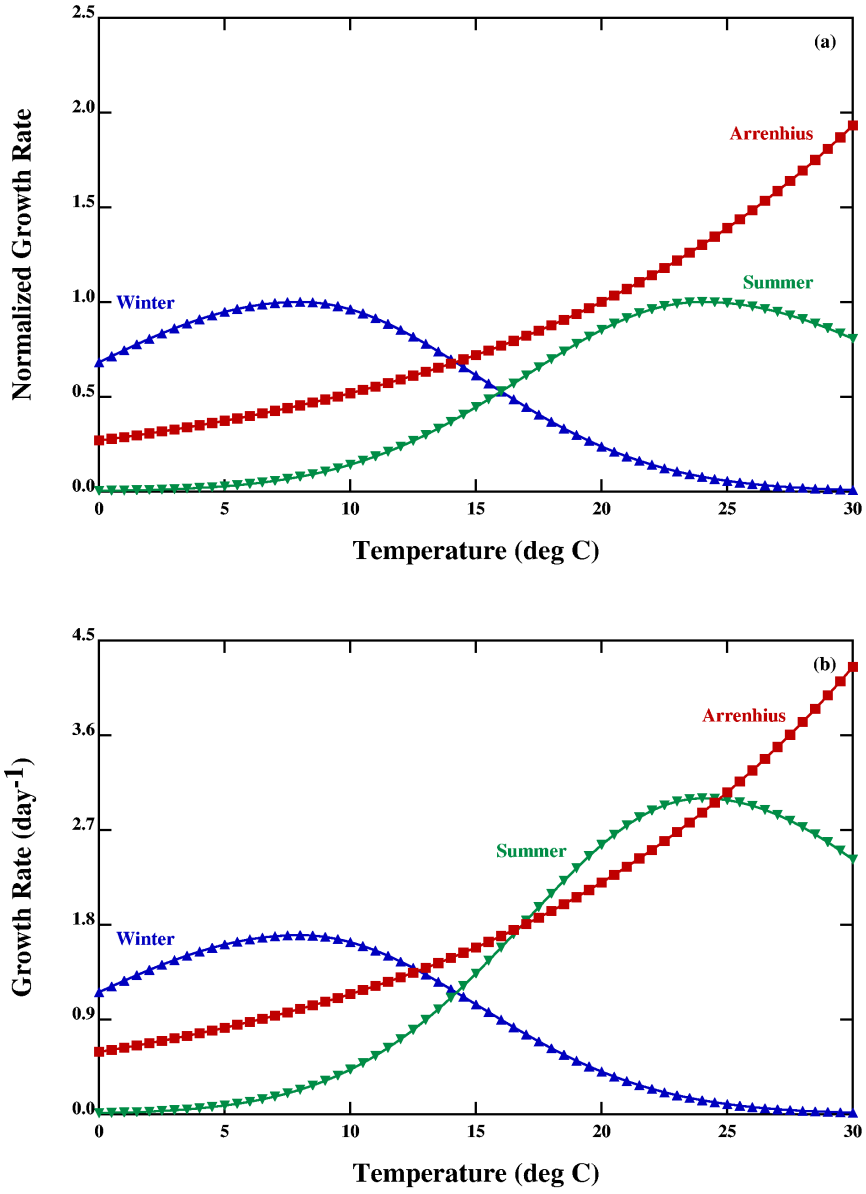


Figure 1-2. Growth Rate as a Function of Temperature

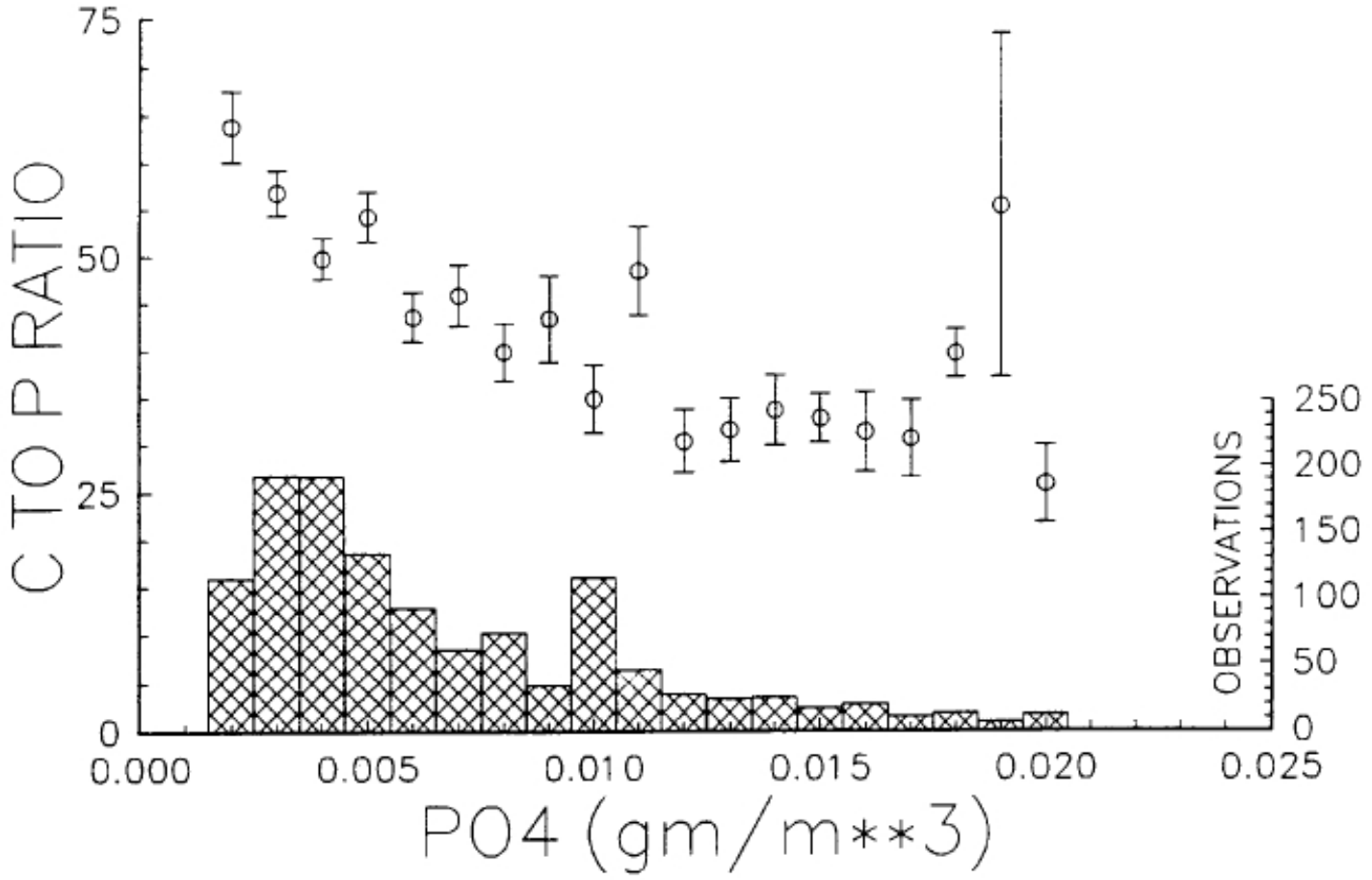


Figure 1-3. Carbon-to-phosphorus ratio (mean and standard error) of seston in Upper Chesapeake Bay. Bars show number of observations.

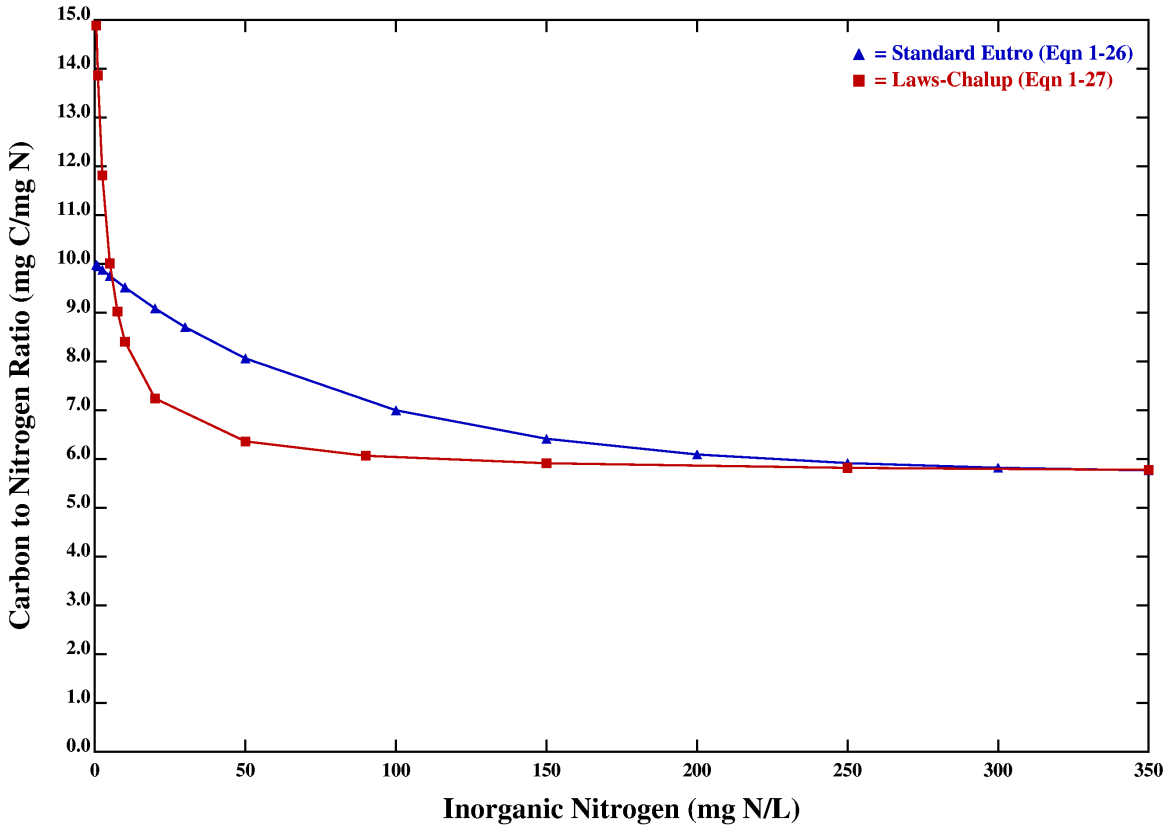
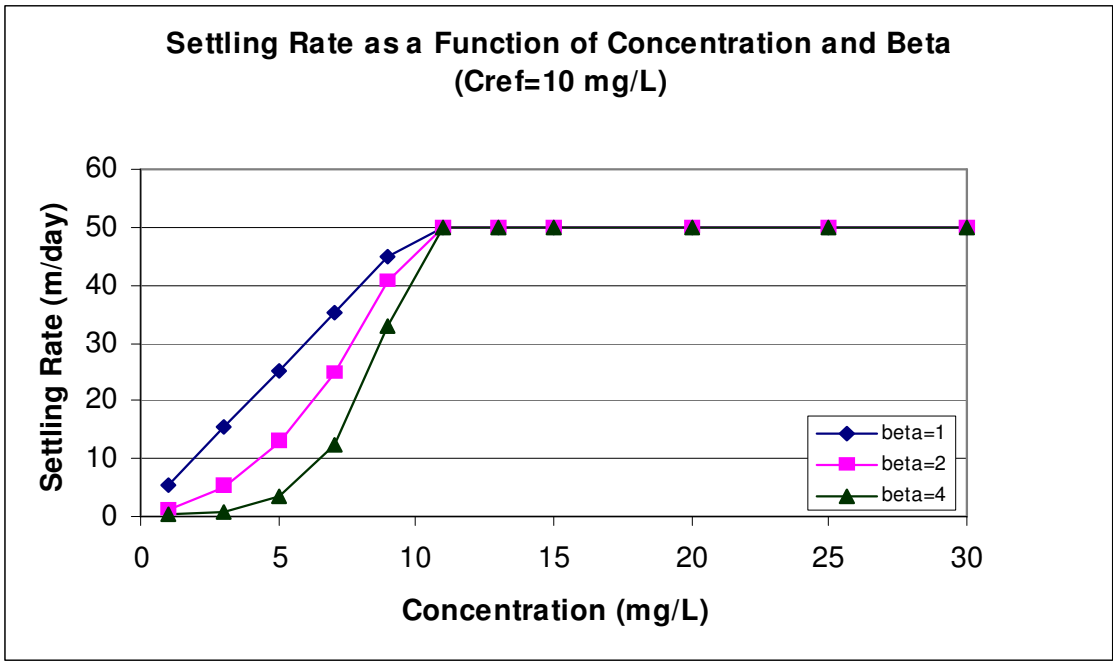


Figure 1-4. Carbon to nitrogen ratios as a function of the concentration of dissolved inorganic nitrogen.



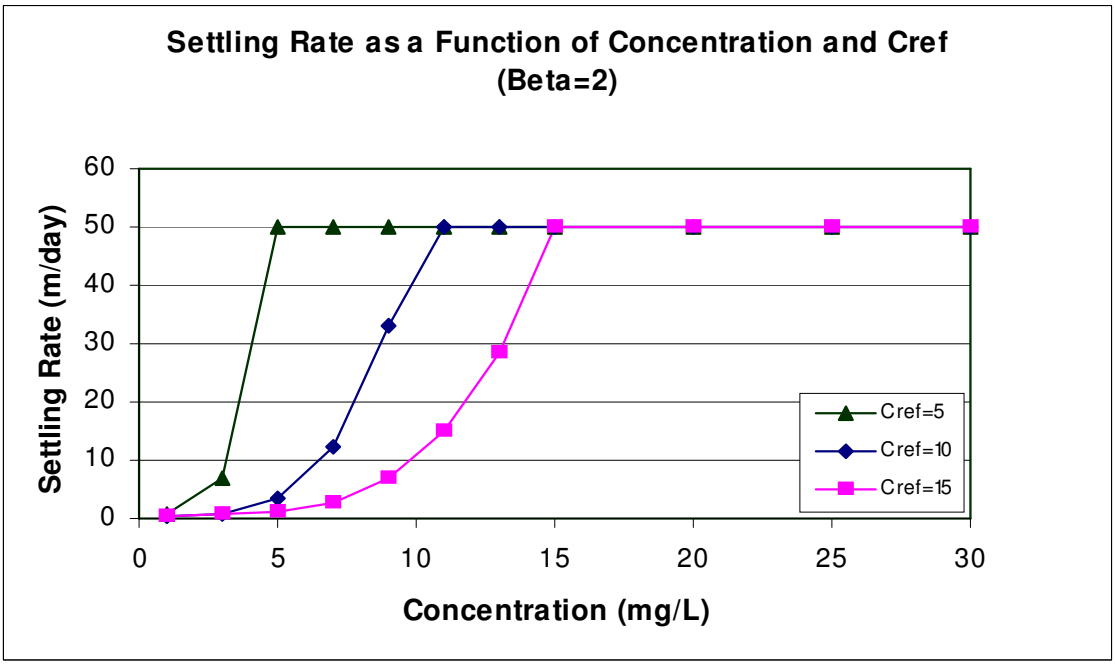


Figure 1-5. Settling Rate as a Function of Concentration and β (Beta) and C_{ref}

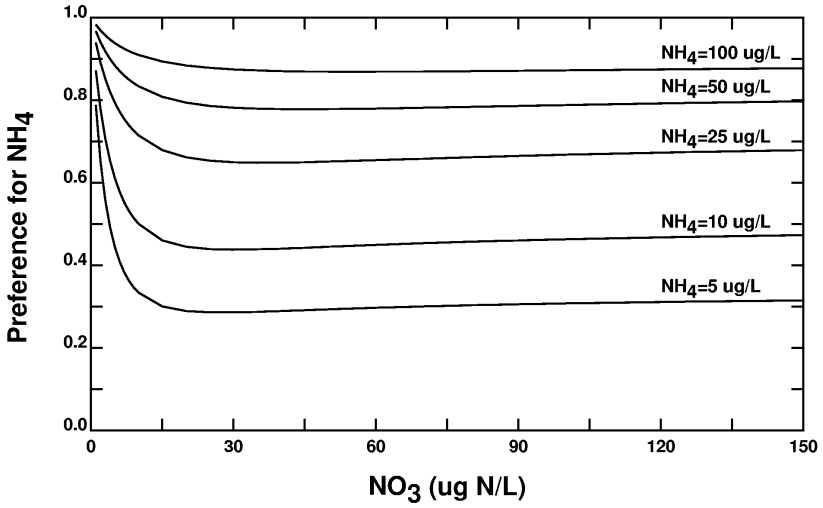


Figure 1-6. Behavior of the Ammonia Preference Structure for Various Concentrations of NH_3 and NO_2+NO_3.

2.0 FRAMEWORK FOR THE SEDIMENT FLUX SUBMODEL

2.1 Overview of Model Framework

The sediment receives fluxes of particulate organic carbon (POC), particulate organic nitrogen (PON), and particulate organic phosphorus (POP). This is collectively referred to as particulate organic matter (POM). Mineralization, which is termed diagenesis, produces soluble end-products. These can react in the aerobic and anaerobic layers of the sediment. The difference between the resulting aerobic layer dissolved concentration and the overlying water concentration determines the flux to or from the sediment. The magnitude of the flux is determined by the surface mass transfer coefficient.

2.2 Diagenesis

The water column model state-variables that are deposited to the sediment include: detrital algae, labile and refractory POC, labile and refractory PON, and labile and refractory POP. The fluxes of these state variables make up the incoming sources of particulate organic matter to the sediment. Carbon, nitrogen, and phosphorus are treated analogously.

The multi-class G model (Westrich and Berner 1984) is used as the basis for the diagenesis of POM. Each class represents a portion of the organic material that reacts at a specific rate. The reaction rates for each class are approximately an order of magnitude smaller than the previous class. For this application three G classes are chosen. The three classes represent three scales of reactivity: reactive (~20 day half life); refractory (~1 year half life); and inert (i.e., conservative). Particulate organic matter is also allowed to be removed by burial.

The kinetic equations for particulate organic carbon, nitrogen, and phosphorus are analogous. Let $G_{POC,i}$ be the concentration of POC in the ith diagenesis class (i=1, 2, or 3). The kinetic equation for diagenesis is:

$$H\frac{dG_{POC,i}}{dt} = -k_{GPOC,i}\,\theta_{GPOC,i}^{T-20}\,G_{POC,i}\,H + J_{GPOC,i}(t) \qquad (2\text{-}1)$$

where:

H	=	depth of the active sediment layer [m],
$G_{POC,i}$	=	concentration of particulate organic carbon in reactivity class i, (g/m^3)
$k_{GPOC,i}$	=	first order reaction rate coefficient ($k_{GPOC,3} = 0$), (/day),

$\theta_{GPOC,i}$ = temperature coefficient,
$J_{GPOC,i}(t)$ = POC flux of the ith G class to the sediment from the overlying water, (g/m^2-day).

The water column sources that contribute to each reactivity class are:

$$J_{GPOC.1} = f_{G1} J_{POC}$$
$$J_{GPOC,2} = f_{G2} J_{POC}$$
$$J_{GPOC,3} = f_{G3} J_{POC}$$

where:

f_{G1} = fraction of water column POC that is in reactivity class G_1
f_{G2} = fraction of water column POC that is in reactivity class G_2
f_{G3} = fraction of water column POC that is in reactivity class G_3
J_{POC} = total flux of POC from the overlying water column to the sediment bed

Carbon diagenesis flux, J_C, is computed from the rates of mineralization of the labile and refractory G classes. (Note: it is assumed that G_3 carbon is inert; therefore, it does not contribute to carbon diagenesis):

$$J_C = \sum_{i=1}^{2} k_{GPOC,i}\ \theta_{GPOC,i}^{(T-20)}\ G_{POC,i}\ H \qquad (2\text{-}2)$$

Nitrogen and phosphorus are completely analogous.

$$J_N = \sum_{i=1}^{2} k_{GPON,i}\ \theta_{GPON,i}^{(T-20)}\ G_{PON,i}\ H \qquad (2\text{-}3)$$

$$J_P = \sum_{i=1}^{2} k_{GPOP,i}\ \theta_{GPOP,i}^{(T-20)}\ G_{POP,i}\ H \qquad (2\text{-}4)$$

The reaction rates and temperature coefficients are analogous to those listed above for carbon.

2.3 The General Sediment Model Equations

The sediment model is constructed from a mass balance equation in the aerobic layer, denoted as layer 1, and the anaerobic layer, layer 2 (with the overlying water column concentrations denoted using the subscript 0). The equations are expressed in terms of the total concentration of the chemical. The distribution between particulate and dissolved fractions is modeled using a linear partitioning model. The mass balance equations of the model can be expressed in a general form which is quite convenient for numerical solution. The layer 1 and 2 equations are:

$$H_1 \frac{dC_{T1}}{dt} = K_{L01}\left(f_{d1}C_{T1} - C_{d0}\right) + w_{12}\left(f_{p2}C_{T2} - f_{p1}C_{T1}\right) + K_{L12}\left(f_{d2}C_{T2} - f_{d1}C_{T1}\right) - k_1 H_1 C_{T1} + J_{T1} \quad (2\text{-}5)$$

$$H_2 \frac{dC_{T2}}{dt} = -w_{12}\left(f_{p2}C_{T2} - f_{p1}C_{T1}\right) - K_{L12}\left(f_{d2}C_{T2} - f_{d1}C\right) - k_2 H_2 C_{T2} - w_2 C_{T2} + J_{T2} \quad (2\text{-}6)$$

where:

C_{T1} = total concentration in layer 1 [M/L^3],
C_{T2} = total concentration in layer 2 [M/L^3],
f_{d1} = dissolved fraction in layer 1, $\frac{1}{1+ m_2\pi_2}$
f_{p1} = 1 - f_{d1} = particulate fraction in layer 1,
f_{d2} = $\frac{1}{1+ m_2\pi_2}$ dissolved fraction in layer 2,
C_{p2} = $f_{p2}\, C_{T2}$ = particulate concentration in layer 2 [M/L^3],
C_{d0} = dissolved concentration,
J_{T1} = total source into layer 1 [M/L^2-T],
J_{T2} = total source into layer 2 [M/L^2-T],
H_1 = depth of layer 1 [L],
H_2 = depth of layer 2 [L],
K_{L01} = aqueous mass transfer coefficient between layer 1 and the overlying water [L/T],
K_{L12} = aqueous mass transfer coefficient between layer 1 and layer 2 [L/T],
w_{12} = particle mixing velocity between layer 1 and layer 2 [L/T],
w_2 = sedimentation velocity out of layer 2 [L/T],

k_1 = first order decay rate coefficient removal process in layer 1 [T^{-1}],
k_2 = first order decay rate coefficient removal process in layer 2 [T^{-1}].

The dissolved and particulate concentrations and fractions are:

$C_{d1} = f_{d1} C_{T1}$ = dissolved concentration in layer 1 [M/L^3],

$$f_{d1} = \frac{1}{1 + m_1 \pi_1}$$

C_{p1} = $f_{p1}\, C_{T1}$ = particulate concentrations in layer 1 [M/L^3],

C_{d2} = $f_{d2}\, C_{T2}$ = dissolved fraction in layer 2 [M/L^3],

f_{p2} = 1 - f_{d2} = particulate fraction in layer 2,

where:

m_1 = solids concentration in layer 1 (aerobic layer) [M/L^3],
m_2 = solids concentration in layer 2 (anerobic layer) [M/L^3],
π_1 = partition coefficient in layer 1 [L^3/M],
π_2 = partition coefficient in layer 2 [L^3/M].

2.3.1 Surface Mass Transfer Coefficient and Reaction Velocities

The surface mass transfer coefficient, K_{L01}, quantifies the mixing between layer 1 and the overlying water. The critical observation is that it can be related to the sediment oxygen demand, SOD. The SOD is the mass flux of dissolved oxygen into the sediment. Thus, it can be calculated from the mass transfer equation:

$$D_1 \frac{d[O_2]}{dz}\Big|_{z=0} \approx D_1 \frac{[O_2(0)] - [O_2(H_1)]}{H_1} = \frac{D_1}{H_1}[O_2(0)] \qquad (2\text{-}7)$$

where a straight line approximation to the derivative is used. The second equality follows from $[O_2(H_1)] = 0$, since H_1 is the depth of zero oxygen concentration. Therefore, the surface mass transfer coefficient can be expressed as:

$$K_{L01} = \frac{D_1}{H_1} = \frac{SOD}{[O_2(0)]} = s \tag{2-8}$$

which is the ratio of SOD and overlying water oxygen concentration. For notational simplicity this ratio is termed s.

The reaction rate in the aerobic layer is formulated as a conventional first order reaction with reaction rate constant k_1. The term in the layer 1 equation is k_1H_1. The depth of the aerobic zone follows from the definition of the surface mass transfer coefficient: $s = D_1/H_1$. Hence $k_1H_1 = k_1D_1/s$. The reaction velocity, which has units [L/T], is defined as:

$$\kappa_1 = \sqrt{D_1 k_1} \tag{2-9}$$

The square root is used to conform to the parameter group that appears in the spatially continuous form of the model. With these definitions the reaction rate - aerobic layer depth product becomes:

$$K_1H_1 = \frac{\kappa_1^2}{s} \tag{2-10}$$

For convenience of nomenclature only, the reaction velocity in layer 2 may be defined as:

$$\kappa_2 = K_2H_2 \tag{2-11}$$

It has units of [L/T]. However, it is not equivalent to the aerobic layer reaction velocities which include diffusion coefficient as well as a reaction rate constant.

With these definitions the layer 1 and 2 equations become:

$$\begin{aligned} H_1 \frac{dC_{T1}}{dt} &= s\left(f_{d1}C_{T1} - C_{d0}\right) + w_{12}\left(f_{p2}C_{T2} - f_{p1}C_{T1}\right) \\ &\quad + K_{L12}\left(f_{d2}C_{T2} - f_{d1}C_{T1}\right) - \frac{\kappa_1^2}{s} C_{T1} + J_{T1} \end{aligned} \tag{2-12}$$

$$H_2 \frac{dC_{T2}}{dt} = w_{12}\left(f_{d2}C_{T2} - f_{p1}C_{T1}\right) - K_{L12}\left(f_{d2}C_{T2} - f_{d1}C_{T1}\right) - \kappa_2 C_{T2} - w_2 C_{T2} + J_{T2} \quad (2\text{-}13)$$

2.3.2 Particulate Phase Mixing

The rate of mixing of sediment particles by macrobenthos (bioturbation) has been quantified by estimating an apparent particle diffusion coefficient. The variation has been found to be proportional to the biomass of the benthos (Matisoft, 1982). In addition, it has been found that the benthic biomass is correlated to the carbon input to the sediment (Maughan, 1986, Robbins et al., 1989). In order to make the model self consistent - that is to use only internally computed variables in the parameterization - it seems reasonable to assume that benthic biomass is proportional to the labile carbon in the sediment, which is calculated by the model as $G_{POC,1}$. The temperature dependency of particle mixing has been accounted for by using an Arrhenius formulation.

A series of experiments have examined the relationship between particle mixing due to benthic organisms and the overlying water oxygen concentration. There is a general dependency of mixing rate on DO, with the lower rates occurring at the lower DO concentration. This dependency is modeled using a Michaelis Menton expression. The particle mixing mass transfer coefficient that results is:

$$w_{12}^{*} = D_p \frac{\theta_{Dp}^{(T-20)}}{H_2} \frac{G_{POC,1}}{G_{POC,R}} \frac{[O_2(0)]}{K_{M,Dp} + [O_2(0)]} \quad (2\text{-}14)$$

with units [L/T]. The superscript * is used to denote this formulation from the final expression for w_{12} that is developed below. The parameter values are:

D_p = Diffusion coefficient for particle (m^2/d),
θ_{Dp} = Temperature coefficient for D_p
$G_{POC,R}$ = Reference concentration for $G_{POC,1}$ (mg/m^3),
$K_{M,Dp}$ = Particle mixing half saturation constant for oxygen (mg/L).

2.3.3 Benthic Stress

In addition to the reduction in particle mixing velocity due to the instantaneous oxygen concentration, it has been found necessary to include a more lasting effect. In particular, if anoxia occurs the benthic fauna population is reduced or eliminated. This is modeled using a first order differential

equation that accumulates stress, S, when overlying water dissolved oxygen is below the particle mixing half saturation constant for oxygen, $K_{M,Dp}$. Thus:

$$\frac{dS}{dt} = -k_s S + \frac{K_{M,Dp}}{K_{M,Dp} + [O_2(O)]} \tag{2-15}$$

where:

S = Accumulated benthic stress [T],

k_s = First order decay coefficient for accumulated stress [T^{-1}].

The behavior of this formulation can be understood by evaluating the limiting steady state stresses at the two oxygen extremes:

$$[O_2(0)] \to 0 \quad k_s S \to 1 \quad (1 - k_s S) \to 0$$

$$[O_2(0)] \to \infty \quad k_s S \to 0 \quad (1 - k_s S) \to 1$$

Note that as $[O_2(0)]$ approaches zero at the onset of anoxia, the term (1 - k_sS) is the proper variable to quantify the degree of benthic stress. The expression is unitless and requires no additional parameter - for example a half saturation constant for benthic stress. The final formulation for the particle mixing velocity which includes the benthic stress is:

$$w_{12} = w_{12}^{*} \min\{(1 - k_s S)\} \tag{2-16}$$

where w_{12}^{*} is defined above. The stress is continued at its minimum value through the end of the year, in order to conform to the observation that once the benthos has been suppressed by low oxygen, it does not recover until the next year.

2.3.4 Dissolved Phase Mixing

Dissolved phase mixing between layers 1 and 2 is via passive molecular diffusion which is enhanced by the mixing activities of the benthic organisms (bio-irrigation). This is modeled by increasing the diffusion coefficient by a factor of 10 over the molecular diffusion coefficient.

$$K_{L12} = \frac{D_d \theta_{Dd}^{(T-20)}}{H_2} \tag{2-17}$$

D_d = Pore water diffusion coefficient (m^2/day),
θ_{Dd} = Temperature coefficient for D_d.

2.3.5 Solids Burial

The deposition of solids to the sediment causes an increase in the depth of the sediment relative to a fixed datum. If the sediment surface is regarded as the point of reference, then the increase in the depth of sediment is a loss of mass due to burial from the active sediment layer.

w_2 = Sedimentation velocity (m/d)

2.3.6 Active Layer Depth

The active layer depth is chosen to represent the depth of organism mixing. Particles buried below this depth can longer be recycled to the aerobic layer. They are permanently buried.

H_2 = Depth of the anaerobic layer (m)

Table 2-1. Sediment Model Coefficients

Description	Notation	Value	Units
Aerobic layer solids concentration	m_1	0.2-1.2	kg/L
Anaerobic layer solids concentration	m_2	0.2-1.2	kg/L
Particle mixing diffusion coefficient	D_p	0.00006	m^2/d
Sedimentation velocity	w_2	0.25-0.75	cm/yr
Pore water diffusion coefficient	D_d	0.0005-0.0050	m^2/d
Temperature coefficient	θ_{Dp}	1.08-1.10	
Temperature coefficient	θ_{Dd}	1.10-1.117	
Water-sediment diffusion coefficient	D_{d0}	0.001	m^2/d
Temperature coefficient	θ_{Dd0}	1.08	
Reaction velocity for nitrification-saltwater	κ_{nh4}	0.1313	m/d
Reaction velocity for nitrification-freshwater	κ	0.20	m/d
Ammonia partition coefficient	π_{nh4}	1.0	L/kg
Temperature coefficient	θ_{nh4}	1.123	
Nitrification half saturation constant for ammonia	k_{mnh4}	728.	mg N/L
Temperature coefficient	θ_{kmnh4}	1.125	
Nitrification half saturation constant for oxygen	k_{mnh4o2}	0.37	mg O_2/L
Aerobic denitrification velocity-saltwater	κ_{1no3}	1.25	m/d
Aerobic denitrification velocity-freshwater	κ_{1no3}	0.20	m/d
Anaerobic layer reaction velocity	κ_{2no3}	0.25	m/d
Temperature coefficient	θ_{no3}	1.08	
Reaction velocity for dissolved sulfide oxidation in the aerobic layer	κ_{d1}	0.2	m/d
Reaction velocity for particulate sulfide oxidation in the aerobic layer	κ_{p1}	0.4	m/d
Partition coefficient for sulfide in the aerobic layer	π_{1s}	100.	L/kg
Partition coefficient for sulfide in the anaerobic layer	π_{2s}	100.	L/kg
Temperature coefficient	θ_{dp1}	1.08	
Sulfide oxidation normalization constant for oxygen	k_{mhso2}	4.	mg O_2/L
First order reaction rate	k_{si}	0.5-0.75	/day
Silica saturation concentration	c_{sisat}	40000.	µg Si/L
Incremental partition coefficient for silica in the aerobic layer	$\Delta\pi_{1si}$	10.	
Partition coefficient for silica in the anaerobic layer	π_{2si}	100.	L/kg
Depth of sediment layer	h_{20}	0.1	m
Temperature coefficient	θ_{si}	1.10	

Table 2-1. Sediment Model Coefficients (Continued)

Description	Notation	Value	Units
Particulate biogenic silica half saturation constant for dissolution	k_{mpsi}	5.0E+07	mg Si/m^3
Overlying water oxygen concentration at which aerobic layer incremental partitioning starts to decrease	$O_{2critsi}$	2.0	mg O_2/L
Partition coefficient for phosphate in the anaerobic layer	$\pi_1 PO_{4n}$	20-1000	L/kg
Enhanced aerobic layer partition coefficient under fully oxic conditions	$\pi_1 PO_{4m}$	20-300	L/kg
Overlying water oxygen concentration at which aerobic layer incremental partitioning starts to decrease	O_{2crit}	2	mg O_2/L
Particle mixing half saturation constant for oxygen	k_{mo2Dp}	4.0	mg O_2/L
Temperature which benthic community begins to recover after an anoxic event	tempbnth	10.0	˚C
Rate at which benthic stress is dissipated	$k_{bnthstr}$	0.03	/d
Scale factor for enhancement of dissolved phase mixing due to benthic activity	k_{lbnth}	0.0	
Minimum particle mixing coefficient	D_{pmin}	3.0E-06	m2/d
Reaction velocity for methane oxidation in the aerobic layer	κ_{ch4}	0.2	m/d
Temperature coefficient	θ_{ch4}	1.08	
Reaction Rate Constant for Diagenesis -G1	$k_{GPOM,1}$	0.035	/day
Reaction Rate Constant for Diagenesis -G2	$k_{GPOM,2}$	0.0018	/day
Reaction Rate Constant for Diagenesis -G3	$k_{GPOM,3}$	0.0-1.0E-6	/day
Temperature Coefficient for Diagenesis - G1	θ_{G1}	1.10	
Temperature Coefficient for Diagenesis - G2	θ_{G2}	1.15	
Temperature Coefficient for Diagenesis - G3	θ_{G3}	1.17	

Table 2-1. Sediment Model Coefficients (Continued)

Source	Distribution of Water Water Column POM Fractions To Each Class		
	G1	G2	G3
Algal Carbon	0.6	0.2	0.2
Labile Particulate Organic Carbon	1.0	0.0	0.0
Refractory Particulate Organic Carbon	0.0	0.5	0.5
Algal Nitrogen	0.6	0.2	0.2
Labile Particulate Organic Nitrogen	1.0	0.0	0.0
Refractory Particulate Organic Nitrogen	0.0	0.6	0.4
AlgalPhosphorus	0.6	0.2	0.2
Labile Particulate Organic Phosphorus	1.0	0.0	0.0
Refractory Particulate Organic Phosphorus	0.0	0.5	0.5

GROUP P: SEDIMENT MODEL INPUT

P1. Print Options

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
        10          20          30          40
ISEDPRNT  IPRNTSED  TWARPSED    IGDSEDOPT
FORMAT (2I10,6X,A4,I10)
```

ISEDPRNT = sediment print control
- = 0, do not print sediment input
- = 1, print sediment input

IPRNTSED = print interval to save sediment computations (nominal = seconds)

TWARPSED = time-warp or units used for IPRNTSED. Normally IPRNTSED is input in units of seconds. The user may, however, use different units.
- = SECS or secs
- = MINS or mins
- = HRS or hrs
- = DAYS or days

IGDSEDOPT = global dump averaging option
- = 0, no averaging
- = 1, perform averaging

P2. Sediment Depths

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
      10                  80
HSED(1,1)   ... HSED(NX,1)
   .
   .
   .
      10                  80
HSED(1,NY)   ... HSED(NX,NY)
FORMAT (8F10.0)
```

HSED(ISED) = sediment layer depth (cm)

P3. Sediment Initial Conditions

```
                80
          Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
        10
SCALEIC
FORMAT (F10.0)
```

SCALEIC = scale factor for each sediment variable initial conditions

```
          10              20                  80
SCARAY(1,1)   SCARAY(2,1)  ...  SCARAY(NX,1)
     .
     .
     .
            10                        80
SCARAY(1,NY)    ...  SCARAY(NX,NY)
FORMAT (8E10.0)
```

SCARAY(IX,IY) = sediment initial condition for segment (IX,IY)

The comment line SCALEIC and SCARAY are repeated for each of the following variables used in the sediment nutrient flux model. The order of the initial conditions required for the sediment nutrient flux model is as follows:

CTEMP (IX,IY)	=	Initial sediment temperature (ºC)
CPOP (IX,IY, 1)	=	G_1 Particulate Organic Phosphorus, POP ,(mg/m^3)
CPON (IX,IY, 1)	=	G_1 Particulate Organic Nitrogen, PON, (mg/m^3)
CPOC (IX,IY, 1)	=	G_1 Particulate Organic Carbon, POP, (mg/m^3)
CPOP (IX,IY, 2)	=	G_2 POP (mg/m^3)
CPON (IX,IY, 2)	=	G_3 PON, (mg/m^3)
CPOC (IX,IY, 2)	=	G_2 POC, (mg/m^3)
CPOP (IX,IY, 3)	=	G_3 POP, (mg/m^3)
CPON (IX,IY, 3)	=	G_3 PON, (mg/m^3)
CPOC (IX,IY, 3)	=	G_3 POC, (mg/m^3)
PO4T2 (IX,IY)	=	Layer 2 orthophosphate, PO_4, (mg/m^3)
NH4T2 (IX,IY)	=	Layer 2 ammonia, NH_4, (mg/m^3)
NO3T2 (IX,IY)	=	Layer 3 nitrate, NO_3, (mg/m^3)
H2ST2 (IX,IY)	=	Layer 2 hydrogen sulfide (in oxygen equivalents), H_2S, (mg O_2/m^3)
SIT2 (IX,IY)	=	Layer 2 silica, (mg/m^3)
BNTHSTRS (IX,IY)	=	Benthic stress
PO4T1 (IX,IY)	=	Layer 1 orthophosphate, PO_4, (mg/m^3)
NH4T1 (IX,IY)	=	Layer 1 ammonia, NH_4, (mg/m^3)

NO3T1 (IX,IY) = Layer 1 nitrate NO_3, (mg/m^3)
SIT1 (IX,IY) = Layer 1 silica, (mg/m^3)
H2ST1 (IX,IY) = Layer 1 hydrogen sulfide (in oxygen equivalents), H_2S, ($mg O_2/m^3$)
CH4T1 (IX,IY) = Layer 1 total methane (in oxygen equivalents), CH_4, (mgO_2/m^3)
CH4T2(IX,IY) = Layer 2 Total Methane (in oxygen equivalents), CH_4, (mgO_2/m^3)
SO4T2 (IX,IY) = Layer 2 total sulfate (in oxygen equivalents), SO_4, (mgO_2/m^3)

P4. Temperature Diffusion Coefficient, G Component Fractions and Diagenesis Rates

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
DIFFT
FORMAT (F10.0)

DIFFT = Water column-sediment layer temperature diffusion coefficient (cm^2/sec)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SALTSW
FORMAT(F10.0)

SALTSW = salinity concentration for determining whether saltwater or freshwater nitrification and denitrification rates are applied. (If salinity is greater than SALTSW then saltwater values are applied.

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
FRPPH1(1)	FRPPH1(2)	FRPPH1(3)

FORMAT (3F10.0)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
FRPPH2(1)	FRPPH2(2)	FRPPH2(3)

FORMAT (3F10.0)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
FRPPH3(1)	FRPPH3(2)	FRPPH3(3)

FORMAT(3F10.0)

FRPPHI(I) = fractions of algal phosphorus going to G_1, G_2, G_3 sediment organic phosphorus for algal group I.

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30
FRPOP(1)	FRPOP(2)	FRPOP(3)

FORMAT(3F10.0)

FRPOP(I) = fraction of non-algal/detrital POP going to G_1, G_2, G_3 sediment organic phosphorus

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRNPH1(1) FRNPH1(2) FRNPH1(3)
FORMAT (3F10.0)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRNPH2(1) FRNPH2(2) FRNPH2(3)
FORMAT (3F10.0)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRNPH3(1) FRNPH3(2) FRNPH3(3)
FORMAT(3F10.0)

FRNPHI(I) = fraction of algal nitrogen going to G_1, G_2, and G_3 sediment organic nitrogen for algal group I

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRPON(1) FRPON(2) FRPON(3)
FORMAT(3F10.0)

FRPON(I) = fraction of non-algal/detrital PON going to G_1, G_2, and G_3 sediment organic nitrogen

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRCPH1(1) FRCPH1(2) FRCPH1(3)
FORMAT (3F10.0)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRCPH2(1) FRCPH2(2) FRCPH2(3)
FORMAT (3F10.0)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRCPH3(1) FRCPH3(2) FRCPH3(3)
FORMAT(3F10.0)

FRCPHI(I) = fraction of algal carbon going to G_1, G_2, and G_3 sediment organic carbon from algal group I

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20 30
FRPOC(1) FRPOC(2) FRPOC(3)
FORMAT(3F10.0)

FRPOC(I) = fraction of non-algal/detrital POC going to G_1, G_2, and G_3 sediment organic carbon

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60
KPDIAG(1)	DPTHTA(1)	KPDIAG(2)	DPTHTA(2)	KPDIAG(3)	DPTHTA(3)

FORMAT(6F10.0)

KPDIAG(I) = diagenesis reaction rates for POP G_1, G_2 and G_3, respectively, (1/day)
DPTHTA(I) = temperature coefficients for POP G_1, G_2 and G_3, respectively

10	20	30	40	50	60
KNDIAG(1)	DNTHTA(1)	KNDIAG(2)	DNTHTA(2)	KNDIAG(3)	DNTHTA(3)

FORMAT(6F10.0)

KNDIAG(I) = diagenesis reaction rates for PON G_1, G_2 and G_3, respectively, (1/day)
DNTHTA(I) = temperature coefficients for PON G_1, G_2 and G_3, respectively

10	20	30	40	50	60
KCDIAG(1)	DCTHTA(1)	KCDIAG(2)	DCTHTA(2)	KCDIAG(3)	DCTHTA(3)

FORMAT(6F10.0)

KCDIAG(I) = diagenesis reaction rates for POC G_1, G_2 and G_3, respectively, (1/day)
DCTHTA(I) = temperature coefficients for POC G_1, G_2 and G_3, respectively

10	20
KSI	THTASI

FORMAT(2F10.0)

KSI = Diagenesis reaction rate for Si, (1/day)
THTASI = Temperature coefficient for Si

P5. Sedimentation and Particle Mixing Rates

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

```
          10              20                  80
VECTOR(1,1)    VECTOR(2,1)    ...   VECTOR(NX,1)
    .
    .
    .
          10                        80
VECTOR(1,NY)    ...   VECTOR(NX,NY)
FORMAT(8F10.0)
```

Comment and VECTOR(IX,IY) are repeated for the following variables:

VSED(IX,IY)	=	sedimentation velocity, (cm/yr)
VPMIX(IX,IY)	=	solid-phase mixing rate, (m^2/day) - D_p
VDMIX(IX,IY)	=	dissolved-phase mixing rate, (m^2/day) - D_d

P6. Sediment Model Constants

```
              80
        Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
        10          20          30
M1M2OPT   PIESIOPT   PIEPO4OPT
FORMAT(3F10.0)
```

M1M2OPT = M1,M2 input option
= 0, M1 and M2 are spatially constant
= 1, M1 and M2 are spatially variable

PIESIOPT = PIESI input option
= 0, Si partition coefficients are spatially constant
= 1, Si partition coefficients are spatially variable

PIEPO4OPT = PIEPO4 input option
= 0, PO_4 partition coefficients are spatially constant
= 1, PO_4 partition coefficients are spatially variable

If MIM20PT = 0 (spatially constant M1 and M2)

```
              80
        Comment
  FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
 10   20        30        40
M1   M2   THTADp   THTADd
FORMAT(4F10.0)
```

M1 = aerobic layer solids concentration, (kg/l)
M2 = anaerobic layer solids concentration, (kg/l)
THTADp = temperature coefficient for D_p
THTADd = temperature coefficient for D_d

If MIM20PT = 1 (spatially variable M1 and M2)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALE

FORMAT (F10.0)

SCALE = scale factor

10	20	80
M1(1,1)	M1(2,1) . . .	M1(NX,1)
.		
.		
.		
M1(1,NY)	M1(2,NY) . . .	M1(NX,NY)

FORMAT(8F10.0)

M1(IX,IY) = aerobic layer solids concentration for sediment segment IX,IY (kg/L)

10
SCALE

FORMAT (F10.0)

SCALE = scale factor

80
M2(1,1) M2(2,1) . . . M2(NX,1)
.
.
.
M2(1,NY) M2(2,NY) . . . M2(NX,NY)

FORMAT(8F10.0)

M2(IX,IY) = an aerobic layer solids concentration for sediment segment IX,IY (kg/L)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
THTADp	THTADd

FORMAT (2F10.0)

THTADp = temperature coefficient for D_p
THTADd = temperature coefficient for D_d

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20
Dd0	THTADd0

FORMAT(2F10.0)

Dd0 = minimum pore water diffusion coefficient (m^2/day)
THTADd0 = temperature coefficient for Dd0

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60
KAPPNH4S	PIENH4	THTANH4S	KMNH4	THTAKMNH4	KMNH4O2

FORMAT(6F10.0)

KAPPNH4S = nitrification velocity in saltwater, (m/d)
PIENH4 = partition coefficient for nitrogen, (L/kg)
THTANH4S = nitrification temperature coefficient in saltwater
KMN4 = ammonia half saturation constant, (mg N/L)
THTAKMN4 = temperature coefficient
KMNH402 = oxygen half saturation constant, (mg O_2/L)

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10          20
KAPPNH4F    THTANH4F
FORMAT(2F10.0)
```

KAPPNH4F = nitrification velocity in freshwater, (m/d)
THTANH4F = nitrification temperature coefficient in freshwater

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10          20          30
KAPP1NO3S   K2NO3S    THTANO3S
FORMAT(3F10.0)
```

KAPP1NO3S = aerobic denitrification velocity in seawater, (m/d)
K2NO3S = anaerobic layer denitrification rate for seawater, (1/d)
THTANO3S = diagenesis temperature coefficient in seawater

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

```
          10          20          30
KAPP1NO3F   K2NO3F    THTANO3F
FORMAT(3F10.0)
```

KAPP1NO3F = aerobic denitrification velocity in freshwater, (m/d)
K2NO3F = anaerobic layer denitrification rate for freshwater, (1/d)
THTANO3F = diagenesis temperature coefficient in freshwater

```
                  80
Comment
FORMAT (A80)
```

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60
KAPPD1	KAPPP1	PIE1S	PIE2S	THTAPD1	KMHSO2

FORMAT(6F10.0)

KAPPD1 = reaction velocity for dissolved sulfide oxidation in the aerobic layer, (m/day)
KAPPP1 = reaction velocity for particulate sulfide oxidation in the aerobic layer, (m/day)
PIE1S = partition coefficient for sulfide in the aerobic layer, (L/kg)
PIE2S = partition coefficient for sulfide in the aerobic layer, (L/kg)
THTAPD1 = temperature coefficient for sulfide oxidation

KMHSO2 = sulfide oxidation normalization constant for oxygen, (mgO_2/L)

If PIESIOPT =0 (PIE1SI and PIE2SI are spatially constant)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60	70	80
CSISAT	PIE1SI	PIE2SI	KSI	THTASI	KMPSI	OCRITSI	JSIDETR

FORMAT(8F10.0)

CSISAT = silica saturation concentration, (mg Si/L)
PIEISI = partition coefficient for silica in aerobic layers, (L/kg)
PIE2SI = partition coefficient for silica in anaerobic layer, (L/kg)
KSI = first order reaction rate, (1/day)
THTASI = temperature coefficient
KMPSI = half saturation constant, (mg Si/g)
O2CRITSI = overlying water oxygen concentration at which aerobic layer incremental, partitioning starts to decrease (mg O_2/L)
JSIDETR = flux of detrital silica, (mg Si/m^2 - d)

If PIESIOPT =1 (PIE1SI and PIE2SI are spatially variable)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALE
FORMAT (F10.0)

SCALE = scale factor

10 20 80
PIE1SI(1,1) PIE1SI(2,1) . . . PIE1SI(NX,1)
.
.
.
10 80
PIE1SI(1,NY) . . . PIE1SI(NX,NY)
FORMAT (8F10.0)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALE
FORMAT (F10.0)

SCALE = scale factor

10 20 80
PIE2SI(1,1) PIE2SI(2,1) . . . PIE2SI(NX,1)
.
.
.
10 80
PIE2SI(1,NY) . . . PIE2SI(NX,NY)
FORMAT (8F10.0)

PIE1SI(IX,IY) = aerobic layer Si partition coefficient (L/kg)
PIE2SI(IX,IY) = anaerobic layer Si partition coefficient (L/kg)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50	60
CSISAT	KSI	THTASI	KMPSI	O2CRITSI	JSIDETR

FORMAT (6F10.0)

CSISAT = silica saturation concentration, (mg Si/L)
KSI = first order reaction rate, (1/day)
THTASI = temperature coefficient
KMPSI = half saturation constant, (mg Si/g)
O2CRITSI = overlying water oxygen concentration at which aerobic layer incremental, partitioning starts to decrease (mg O_2/L)
JSIDETR = flux of detrital silica, (mg Si/m^2 - d)

If PIEPO4OPT =0 (PIE1PO4M and PIE1PO4N are spatially constant)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40
PIE1PO4M	PIE1PO4N	O2CRIT	KMO2DP

FORMAT(4F10.0)

PIE1PO4M = incremental partition coefficient for phosphate in aerobic layer, (L/kg)
PIE1PO4N = partition coefficient for phosphate in the anaerobic layer, (L/kg)
O2CRIT = overlying water oxygen concentration at which aerobic layer incremental partitioning starts to decrease, (mg O_2/L)
KMO2DP = half saturation constant, (mg Si/g)

If PIEPO4OPT = 1 (PIE1PO4 and PIE2PO4 are spatially variable)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALE

FORMAT (F10.0)

SCALE = scale factor

10 20 80
PIE1PO4(1,1) PIE1PO4(2,1) . . . PIE1PO4(NX,1)
.
.
.
10 80
PIE1PO4(1,NY) . . . PIE1PO4(NX,NY)
FORMAT (8F10.0)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10
SCALE
FORMAT (F10.0)

SCALE = scale factor

10 20 80
PIE2PO4(1,1) PIE2PO4(2,1) . . . PIE2PO4(NX,1)
.
.
.
10 80
PIE2PO4(1,NY) . . . PIE2PO4(NX,NY)
FORMAT (8F10.0)

PIE1PO4(IX,IY) = aerobic layer PO4 partition coefficient (L/kg)
PIE2PO4(IX,IY) = anaerobic layer PO4 partition coefficient (L/kg)

80
Comment
FORMAT (A80)

Comment = Comment line (ignored by RCA)

10 20
02CRIT KMO2DP

O2CRIT = overlying water oxygen concentration at which aerobic layer incremental partitioning starts to decrease (mg O_2/L)
KMO2Dp = half saturation constant for particle mixing (mgO_2/L)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40
TEMPBNTH	KBNTHSTR	KLBNTH	DPMIN

FORMAT(4F10.0)

TEMPBNTH = benthic temperature switch (°C)
KBNTHSTR = benthic stress decay rate constant (1/day)
KLBNTH = benthic stress enhancement constant
DPMIN = minimum value for physical benthic mixing, (m^2/day)

80
Comment

FORMAT (A80)

Comment = Comment line (ignored by RCA)

10	20	30	40	50
KAPPCH4	THTACH4	KMCH402	KMSO4	SO4OMG

FORMAT(5F10.0)

KAPPCH4 = reaction velocity for methane production (??/day)
THTACH4 = temperature coefficient for methane production
KMCH4O2 = half saturation coefficient for methane production (mg O2/L)
KMS04 = half saturation coefficient for sulfate (mg/L)
SO4OMG = overlying water sulfate concentration (mg s/L)

Table 2-2 presents a sample input deck for the sediment model coefficient set.

TABLE 2-2. SAMPLE INPUT DECK FOR THE SEDIMENT MODEL COEFFICIENT SET

```
C ISEDPRNT  IPRNTSED  TWARPSED IGDSEDOPT
          0    864000      SECS         1
C  Sediment depths (cm)
       0.       0.00       0.0       0.0
       0.      10.00      10.0       0.0
       0.      10.00      10.0       0.0
       0.       0.00       0.0       0.0
C  scale factor / temperature initial conditions (Deg C)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0       3.2       3.2       0.0
       0.0       3.2       3.2       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G1 POP initial conditions (mg P/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0     1320.     1320.       0.0
       0.0     1320.     1320.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G1 PON initial conditions (mg N/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    12400.    12400.       0.0
       0.0    12400.    12400.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G1 POC initial conditions (mg C/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    61400.    61400.       0.0
       0.0    61400.    61400.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G2 POP initial conditions (mg P/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0     8680.     8680.       0.0
       0.0     8680.     8680.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G2 PON initial conditions (mg N/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    92700.    92700.       0.0
       0.0    92700.    92700.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G2 POC initial conditions (mg C/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0   410000.   410000.       0.0
       0.0   410000.   410000.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G3 POP initial conditions (mg P/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    58100.    58100.       0.0
       0.0    58100.    58100.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G3 PON initial conditions (mg N/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0   480000.   480000.       0.0
       0.0   480000.   480000.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / G3 POC initial conditions (mg C/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0  4210000.  4210000.       0.0
       0.0  4210000.  4210000.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Biogenic Si initial conditions (mg Si/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0  5470000.  5470000.       0.0
       0.0  5470000.  5470000.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Layer 2 Total Inorganic PO4 (mg P/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    11500.    11500.       0.0
       0.0    11500.    11500.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Layer 2 Total NH4 (mg N/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0     8770.     8770.       0.0
```

TABLE 2-2. SAMPLE INPUT DECK FOR THE SEDIMENT MODEL COEFFICIENT SET (Cont.).

```
      0.0     8770.     8770.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Layer 2 Nitrate (mg N/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0      250.      250.       0.0


       0.0      250.      250.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Layer 2 Total Sulfide (as O2 equivalents) (mg O2/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0     1180.     1180.       0.0
       0.0     1180.     1180.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Layer 2 Total Inorganic Si (mg Si/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    22700.    22700.       0.0
       0.0    22700.    22700.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Benthic Stress initial conditions
 0.100E+01
       0.       0.00       0.0       0.0
       0.      11.00      11.0       0.0
       0.      11.00      11.0       0.0
       0.       0.00       0.0       0.0
C  scale factor / Layer 1 Total Inorganic PO4 (mg P/m**3)
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0    16000.    16000.       0.0
       0.0    16000.    16000.       0.0
       0.0       0.0       0.0       0.0
C  scale factor / Layer 1 Total Inorganic NH4 (mg N/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.       35.0       35.       0.0
       0.       35.0       35.       0.0
       0.        0.0       0.0       0.0
C  scale factor / Layer 1 NO3 (mg N/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.       343.      343.       0.0
       0.       343.      343.       0.0
       0.        0.0       0.0       0.0
C  scale factor / Layer 1 Total Inorganic Si (mg Si/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.      8000.     8000.       0.0
       0.      8000.     8000.       0.0
       0.        0.0       0.0       0.0
C  scale factor / Layer 1 Sulfide (in oxygen equivalents) (mg O2/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.       0.02      0.02       0.0
       0.       0.02      0.02       0.0
       0.        0.0       0.0       0.0
C  scale factor / Layer 1 Methane (in oxygen equivalents) (mg O2/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.       0.02      0.02       0.0
       0.       0.02      0.02       0.0
       0.        0.0       0.0       0.0
C  scale factor / Layer 2 Methane (in oxygen equivalents) (mg O2/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.        5.0       5.0       0.0
       0.        5.0       5.0       0.0
       0.        0.0       0.0       0.0
C  scale factor / Layer 2 Sulfate (in oxygen equivalents) (mg O2/m**3)
 0.100E+01
       0.        0.0       0.0       0.0
       0.        0.9       0.9       0.0
       0.        0.9       0.9       0.0
       0.        0.0       0.0       0.0
C    Difft
   0.00180
C   SALTSW
      0.00                            SALTSW
C FRPPH1-G1 FRPPH1-G2 FRPPH1-G3     fractions to G1, G2, G3 P for Algal Group 1
     0.650     0.200     0.150      FRPPH1 (G1,G2,G3)
C FRPPH2-G1 FRPPH2-G2 FRPPH2-G3     fractions to G1, G2, G3 P for Algal Group 2
```

TABLE 2-2. SAMPLE INPUT DECK FOR THE SEDIMENT MODEL COEFFICIENT SET (Cont.).

```
     0.650     0.200     0.150     FRPPH2 (G1,G2,G3)
C FRPPH3-G1 FRPPH3-G2 FRPPH3-G3    fractions to G1, G2, G3 P for Algal Group 3
     0.650     0.200     0.150     FRPPH2 (G1,G2,G3)
C FRPOP-G1  FRPOP-G2  FRPOP-G3    fractions to G1, G2, G3 P for detrital POP
     0.650     0.200     0.150     FRPOP (G1,G2,G3)
C FRNPH1-G1 FRNPH1-G2 FRNPH1-G3    fractions to G1, G2, G3 N for Algal Group 1
     0.650     0.250     0.100     FRNPH1 (G1,G2,G3)
C FRNPH2-G1 FRNPH2-G2 FRNPH2-G3    fractions to G1, G2, G3 N for Algal Group 2
     0.650     0.250     0.100     FRNPH2 (G1,G2,G3)
C FRNPH3-G1 FRNPH3-G2 FRNPH3-G3    fractions to G1, G2, G3 N for Algal Group 3
     0.650     0.250     0.100     FRNPH2 (G1,G2,G3)
C FRPON-G1  FRPON-G2  FRPON-G3    fractions to G1, G2, G3 N for detrital PON
     0.650     0.250     0.100     FRPON (G1,G2,G3)
C FRCPH1-G1 FRCPH1-G2 FRCPH1-G3    fractions to G1, G2, G3 C for Algal Group 1
     0.650     0.200     0.150     FRCPH1 (G1,G2,G3)
C FRCPH2-G1 FRCPH2-G2 FRCPH2-G3    fractions to G1, G2, G3 C for Algal Group 2
     0.650     0.200     0.150     FRCPH2 (G1,G2,G3)
C FRCPH3-G1 FRCPH3-G2 FRCPH3-G3    fractions to G1, G2, G3 C for Algal Group 3
     0.650     0.200     0.150     FRCPH2 (G1,G2,G3)
C FRPOC-G1  FRPOC-G2  FRPOC-G3    fractions to G1, G2, G3 C for detrital POC
     0.650     0.200     0.150     FRPOC (G1,G2,G3)
C KPDIAGG1   THETAG1  KPDIAGG2   THETAG2  KPDIAGG3   THETAG3    POP Diag Rates
 0.0350000     1.100 0.0018000     1.150 0.0000010     1.170
C KNDIAGG1   THETAG1  KNDIAGG2   THETAG2  KNDIAGG3   THETAG3    PON Diag Rates
 0.0350000     1.100 0.0018000     1.150 0.0000010     1.170
C KCDIAGG1   THETAG1  KCDIAGG2   THETAG2  KCDIAGG3   THETAG3    POC Diag Rates
 0.0350000     1.100 0.0018000     1.150 0.0000010     1.170
C  KSiDiag     THETA                                      Biogenic Diag Rate
     0.500     1.100
C   Sedimentation or Burial Rates  (cm/yr)
C Scale Factor
 0.100E+01
       0.       0.00       0.0       0.0
       0.      0.250      0.25       0.0
       0.      0.250      0.25       0.0
       0.       0.00       0.0       0.0
C   Particle or solid phase mixing rate (m2/day)
C Scale Factor
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0 0.120E-03 0.120E-03       0.0
       0.0 0.120E-03 0.120E-03       0.0
       0.0       0.0       0.0       0.0
C   Dissolved phase mixing rate (m2/day)
C Scale Factor
 0.100E+01
       0.0       0.0       0.0       0.0
       0.0 0.100E-02 0.100E-02       0.0
       0.0 0.100E-02 0.100E-02       0.0
       0.0       0.0       0.0       0.0
C  M1M2OPT  PIESIOPT PIEPO4OPT   (0=spatially constant,1=variable)
         0         0         0
C       M1        M2   ThetaDp   ThetaDd
     0.500     0.500    1.1500    1.1500
C      Ddo  ThetaDdo
    0.0010    1.0800
C KappNH4S    PIENH4 ThetaNH4S     KMNH4 ThtaKmNH4   KMNH4O2    (saltwater values)
    0.1313    1.0000    1.0800  728.0000    1.1250    0.7400
C KappNH4F ThetaNH4F    (freshwater values)
    0.2000    1.0800
C KappNO3S    K2NO3S ThetaNO3S    (saltwater values)
    0.0500    0.1000    1.3000
C KappNO3F    K2NO3F ThetaNO3F    (freshwater values)
    0.1000    0.2500    1.0800
C   Kappd1    Kappp1     PIE1S     PIE2S  ThetaPD1    KMHSO2
    0.2000    0.4000  100.0000  100.0000    1.0800    4.0000
C   CSiSat    PIE1Si    PIE2Si       KSi   ThetaSi     KMPSi  O2CritSi   JsiDetr
40000.0000    15.000    100.00    0.5000    1.1000   5.0E+07    2.0000      060.
C  PIEPO4M  PIE1PO4N    O2Crit    KMO2Dp
      20.0      20.0      2.00      4.00
C TempBnth  KBnthStr    K1Bnth     Dpmin
   10.0000    0.0300    0.0000    0.0000
C  KappCh4  ThetaCh4   KMCH4O2     KMSO4
      0.20      1.08      0.20      0.10
```

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APPENDIX B

PATHOGEN MODEL

PATHOGEN MODEL

Despite significant efforts and expenditures by federal, state, and local government to reduce the sources of pathogenic bacteria, associated with human health risks and diseases, to receiving waters, pathogens continue to be an issue when trying to meet the "swimmable" goals of the Clean Water Act. This is particularly the case for waters that receive combined sewer overflows (CSOs) from the nation's larger and older cities, wherein both sanitary and stormwater are conveyed in the same sewer system. However, modeling of the major waterborne pathogens of concern (including *V. Cholerae, Salmonellae, and Shigella* species) is usually not practiced due to the difficulty in measuring these organisms directly in the receiving waters. Rather surrogate indicator organisms, such as total and fecal coliform are modeled. More recently, through the Coastal Health Act of 2000, the USEPA is requiring that the coastal states implement the enterococci criteria for marine waters originally developed in the 1986 "Ambient Water Quality Criteria for Bacteria - 1986" guidance document. Therefore, the pathogen model developed by HydroQual includes state-variables for total and fecal coliform and enterococcus.

The mathematical framework employed in the pathogen model is the same mass-balance approach detailed in Appendix A - Integrated Eutrophication and Sediment Nutrient Flux Model, only the state-variables and reaction rates differ. The pathogen model includes the following state-variables:

1. Salinity (ppt)
2. Tracer (mg/L)
3. Total Coliform Bacteria (#/100 mL)
4. Fecal Coliform Bacteria (#/100 mL)
5. Enterococci (#/100 mL)

Note: when inputting loads of coliform bacteria or enterococci, the user should use the following procedure:

bacterial load = wastewater (or CSO) flow * coliform concentration * conversion factor

where the coliform concentration is in units of #/100 mL and the conversion factor is:

Units of wastewater flow	Conversion factor
m^3/day	0.001
m^3/sec	86.4
MGD	3.785
cfs	2.446

At the present time, the HydroQual pathogen model only incorporates a first-order decay or die-off rate for coliform bacteria and enterococcus. The model does not account for any post-discharge growth of the organisms in the receiving water. The tracer variable is included in the model framework should the user wish to "tag" or follow the spatial distribution of a particular WWTP(s), CSO(s), or separate sewer overflow (SSOs). The present framework permits the coliform/enterococcus die-off rate to be a function of temperature, sunlight, and, for estuarine/coastal systems, salinity. The following equation represents the die-off rate for total and fecal coliform and entrerococcus:

$$k_{die-off} = (k_{base} + k_{sal}(S)) \cdot \theta_{sal}^{(T-20)} + k_{light} \cdot f(I) \quad (1)$$

where:

$k_{die-off}$	=	composite die-off rate (/day),
k_{base}	=	base die-off rate (/day),
k_{sal}	=	salinity dependent die-off rate (/ppt-day),
S	=	concentration of salinity (ppt),
θ	=	temperature correction coefficient for die-off rate,
T	=	temperature (deg C),
k_{light}	=	light-dependent die-off rate (ly-day),
f(I)	=	depth- and time-integrated light intensity (ly).

The function, f(I), may be evaluated as follows:

$$f(I) = \frac{I_0(t)}{K_e H}(1 - \exp(-K_e H)) \quad (2)$$

where:

$I_0(t)$	=	solar radiation at water surface (or at surface of model segment if water column is vertically segmented), (ly),
K_e	=	extinction coefficient (/m),
H	=	depth of water column (or depth of model segment if the water column is vertically segmented in the model) (m).

The following presents the structure of the parameters, constants, and time-variable functions input file for running the pathogen model.

2-D Parameters

Number	Name		Description
1	KEBS	=	extinction coefficients (used when KEOPT = 1 or 3) (/m),

Constants

Number	Name		Description
1	KCBC	=	base die-off rate for coliform bacteria at 20 deg C (/day),
2	KCBT	=	temperature correction coefficient,
3	KCSAL	=	salinity-dependent coliform die-off rate (/ppt-day),
4	KCLGHT	=	sunlight-dependent coliform die-off rate (/ly-day),
5	SOLAR	=	option to include sunlight-dependent die-off rate, = 0, do not include sunlight effects on die-off rate, = 1, include sunlight effects on die-off rate,
6	KEBC	=	base die-off rate for enterococcus at 20 deg C (/day),
7	KEBT	=	temperature correction coefficient,
8	KESAL	=	salinity-dependent enterococcus die-off rate (/ppt-day),

9	KELGHT	=	sunlight-dependent coliform die-off rate (/ly-day),
10	KEOPT	=	method for inputting extinction coefficients,
		= 0,	K_e is a constant (i.e., spatially and temporally invariant),
		= 1,	K_e is spatially variable, but constant in time (uses the 2-D parameter, KEBS)
		= 2,	K_e is time-variable (uses the time-variable function KETVF), but spatially invariant,
		= 3,	K_e is spatially variable and can vary in time, using the 2-D parameter, KEBS, and the time-variable function, KETVF,
		= 4,	K_e is fully variable in time and space, with input coming from a separate input file (kebs.inp),
11	KECONST	=	base extinction coefficient (used when KEOPT = 0 or 2) (/m),

Time-Variable Functions

Number	Name		Description
1	ITOTSF	=	total daily solar radiation (used when KEOPT = 2,3 or 4) (/m),
2	F	=	fraction of daylight (used when KEOPT = 2, 3, or 4),
3	KETVF	=	time-variable scaling factor for extinction coefficients (used when KEOPT = 2 or 3).

APPENDIX C

RESIDENCE TIME/TRACER MODEL

RESIDENCE TIME/DYE-TRACER SUBROUTINE

One method for determining whether the transport fields computed by the hydrodynamic model, which are to be used to advect and disperse water quality variables of interest within RCA, are correct is to compare them to observed data. For estuarine systems, these comparisons are usually made using observed water elevations, current meter data, and salinity, temperature, and density data. However, in addition, in special cases tracers, such as Rhodamine dye or SF_6 (sulfur hexafluoride, are used to provide data sets for calibration of hydrodynamic models, particularly when applied to freshwater systems.

In addition, it is often useful to know the residence time of a region or portion of a waterbody. This information can be used to estimate how quickly a contaminant is flushed from that region or portion of the study domain. One way of determining the residence time of the region of interest is to perform model simulations using "conservative tracers or dyes."

Therefore, a TUNER subroutine has been developed that can be used to simulate the transport of a tracer within a study domain and that can be used to estimate the residence time of the tracer within a portion of the model domain or within the entire model domain. The mathematical framework employed in the tracer model is the same mass-balance approach detailed in Appendix A - Integrated Eutrophication and Sediment Nutrient Flux Model, only the state-variables differ. The tracer model has only one state-variable - the tracer or dye (actually the code provided can be quickly expanded to include three tracers or dyes by "un-Commenting" some of the FORTRAN code):

1. Tracer (mg/L)

The residence time or dye model is set up so that, in addition to putting a tracer or dye within the entire model domain, one can initialize only a portion of the model domain with the tracer and then have the model determine (1) the mass of tracer remaining within the initialized portion of the model domain, (2) a user specified portion of the model domain, as well as, (3) the mass of tracer left within the entire model domain. One can then post-process the model outputs to estimate the residence time of the dye using the commonly accepted definition of one *e*-folding time (one *e*-folding is defined as exp(-1) or the time at which 0.3679 of the initial mass remains within the region or the study domain).

The following presents the structure of the parameters, constants, and time-variable functions input file for running the pathogen model.

3-D Parameters

Number	Name		Description
1	DYE1IC3	=	initial conditions for tracer or dye (mg/L),
2	DOMAIN1	=	region of interest for determining residence time

2-D Parameters

Number	Name		Description
1	DYE1IC2	=	initial conditions for tracer or dye (mg/L),
2	DOMAIN1	=	region of interest for determining residence time

Constants

Number	Name	Description
1	DYEDIS1	= dye distribution option, = 0, assign initial tracer concentrations uniformly in the vertical plane of the model as determined by the 2-D parameter DYE1IC2 = 1, assign initial tracer concentrations on a model segment by model segment basis as determined by the 3-D parameter DYE1IC3 (permits one to look at residence time of surface layer versus bottom layer)
2	TIMEDYE1	= time to release the tracer or dye (days),
3	DECAY1	= decay rate of tracer or dye (1 day)

Time-Variable Functions

No time-variable functions are required.

APPENDIX D

DESCRIPTION OF RCA OUTPUT FILE FORMATS

FILE DESCRIPTIONS FOR RCAF OUTPUT FILES
VERSION 3.0 OF RCA

The water quality modeling program, RCA, creates a number of output files (known as RCAF files) containing various types of model computations that (1) can be visualized by the user via GDP or other post-processing software, (2) can be used to "cycle" model runs, and (3) can provide for mass balance and flux balance analyses of a system. Currently there are four types of files saved by RCA: (1) global dump or map files, (2) detailed dump or history files, (3) "end of simulation" concentration files, and (4) mass balance and flux balance files. The global or map file provide a snapshot of the entire model domain for the key water quality variables, while the detailed or history file provides more "detailed" information about the model simulation for a more limited number of model segments within the model domain. The "end of simulation" concentration files contain the concentrations for all model segments for all systems at the end of the simulation. These files can be used by the user to cycle or "hot-start" a subsequent simulation, if one desires the model to achieve a "new" dynamic equilibrium in response to reductions in pollutant inputs or a management scenario. The mass balance/flux balance files provide information that permits a user to develop a mass balance analysis for a system or to perform a flux balance analysis in a certain portion(s) of the model domain. In order to restrain the physical size of each of the RCAF files, and thus reduce required physical disc-size requirements, all RCAF files are written in binary (rather than ASCII format). The following provides a more detailed description of the content and 'format' of each of the RCAF output files.

Global Dump Files - RCAF10 and RCAF11

The RCAF10 file provides information concerning the size of the model, the number of systems, the number of global dumps saved, the variable names, and the times for which the global information was saved. The RCAF11 file contains the concentrations of the key water quality variables within the model domain.

RCAF10 (internal RCA file number 10)

Record 1: NX,NY,NZ,NOSYS,NGDMP

where:
- NX — number of computational elements in the x-direction (Integer)
- NY — number of computational elements in the y-direction (Integer)
- NZ — number of vertical layers (Integer)
- NOSYS — number of state-variables in the model (Interger)
- NGDMP — number of global dumps saved by the kinetic subroutine in RCAF11 (Integer)

Record 2: SYNAME(NGDMP)

where:
- SYNAME — a vector (NGDMP elements long) that contains the names of the water quality parameters saved in the RCAF11 file (Character*8)

Record 3: SYSGDP(40)

where:
- SYSGDP — a vector (40 elements long) that contains the system bypass information for the model run (Integer*2). Used primarily by HydroQual's in-house post-processing software.

Record 4: FSM(NX,NY)
where: FSM an array (NX x NY) containing the land-mask information for the model grid (Real). The following convention is used: water=1, land=0, boundaries=-1 or -2.

Records 5 -> TIME
where: TIME times at which the global dumps were written to the disk. Number of records = (total length of the simulation time ÷ global dump interval) + 1 (for the initial conditions).

RCAF11 (internal RCA file number 11)
Records 1 -> CARAY
where CARAY arrays (each NX x NY x NZ) containing the concentrations for each model segment in the model domain for each water quality variable of interest (Real). Record 1 contains the CARAY for variable 1, record 2 for variable 2, ..., record NGDMP for variable NGDMP. Record NGDMP+1 starts with variable 1 again, but for the next time record.

Detailed Dump Files - RCAF12 and RCAF13

RCAF12 (internal RCA file number 12)
Record 1: NDMPS
where NDMPS number of segments selected for saving detailed dumps (Integer).

Record 2: ((IFDMPS(I,J),J=1,3),I=1,NDMPS)
where IFDMP(I,J) contains the x cell number (j=1), the y cell number (j=2), and the z or sigma-layer cell number (j=3) for each of the segments saved (Integer).

Record 3: DDGDPBY(40)
where: DDGDPBY a vector (40 elements long) that contains the system bypass information for the model run (Integer*2). Used primarily by HydroQual's in-house post-processing software.

Record 4: DDNAMES(NOSYS,5)
where: DDNAMES a vector (NOSYS x 5 elements long) that contains the names of the water quality parameters saved in the RCAF13 file (Character*8). Each model system or state-variables has provision for saving 5 pieces or information (state-variable concentrations, combinations of state-variables, reaction terms, etc.). The specific information saved for each system is determined in the user's kinetic subroutine TUNER.

Record 5 -> TIME
where: TIME times for which the detailed dumps were saved (Real).

RCAF13 (internal RCA file number 13)

Records 1 -> BUFFER(50000)

where: BUFFER an array (50000 elements long) containing the detailed dumps (Real). The information for each system is packed into the 'buffer' as follows (assume NOSYS=25):

BUFFER(1-5) = the five pieces of information for the first IFDMP for system 1
BUFFER(6-10) = the five pieces of information for the first IFDMP for system 2
.
.
.
BUFFER(121-125) = the five pieces of information for the first IFDMP for system 25
BUFFER(126-130) = the five pieces of information for the second IFDMP for system 1
BUFFER(131-135) = the five pieces of information for the second IFDMP for system 2
.
.
.
BUFFER(246-250) = the five pieces of information for the second IFDMP for system 25
BUFFER(251-255) = the five pieces of information for the third IFDMP for system 1
BUFFER(256-260) = the five pieces of information for the third IFDMP for system 2
etc.

Note: not all of the buffer will be used, only NDMPS*5*NOSYS elements contain actual model computations (the remaining values should be zero).

Sediment Dump File - RCAF14

The RCAF14 file contains information from the sediment flux model (SFM) if used. RCAF14 looks like a global dump or map file, since it contains information generated by the SFM for all active model segments in the model domain (note: only the water segments corresponding to FSM(I,J)=1).

RCAF14 (internal RCA file number 14)

Record 1: FSM(NX,NY)

where: FSM an array (NX x NY) containing the land-mask information for the model grid (Real). The following convention is used: water=1, land=0, boundaries=-1 or -2.

Records 2 -> TIME,(SED(I),I=1,76)

where: TIME times at which the SFM info was saved (REAL)

SED a vector (76 elements long) containing information generated by the sediment flux model (REAL). The SED information is written for each active (FSM=1) segment using the following DO-loop sequence:

```
DO ICOL=1,NY
  DO IROW=1,NX
       WRITE(14)  TIME,SED
  ENDDO
ENDDO
```

The following NAMES have been assigned to the SED vector:

SED(1-5): ctemp,pop1r,pop2r,pop3r,popr
SED(6-10): pon1r,pon2r,pon3r,ponr,poc1r
SED(11-15): poc2r,poc3r,pocr,po4t2r,hst2r
SED(16-20): sit2r,psiavr,jpop,jpon,jpoc
SED(21-25): o20,csod,sod,s,jdiagp
SED(26-30): jdiagn,jdiagc,jo2nh4,xjco2av,xjc1av
SED(31-35): jpo4,jnh4,jno3,jhs,jsi
SED(36-40): jch4aq,jch4g,h1,po40,po41
SED(41-45): po42,po4t2,nh40,nh41,nh42
SED(46-50): nh4t2,no30,no31,no32,no3t2
SED(51-55): hs1,hs2,hst2,si0,si1
SED(56-60): si2,sit2,bnthden,ch41,ch42
SED(61-65): ch4t2,so41,so42,so4t2,flxpopG1
SED(66-70): flxpopG2,flxpopG3,flxponG1,flxponG2,flxponG3
SED(71-75): flxpocG1,flxpocG2,flxpocG3,flxpos,flxpo4t2s
SED(76): flxsit2s

RCA "Hot-Start" Files - RCAFIC and RCAFICSED

The RCAFIC file is used to save the "end of simulation" water column concentrations for use as initial conditions if the user chooses to perform a cycled (or "hot-start") run, while the RCAFICSED file contains similar information but for the sediment nutrient flux model (if used).

RCAFIC (internal RCA file number 15)

Record 1: CARAY

where CARAY an array (NX x NY x NZ x NOSYS) containing the concentrations for each model segment/system in the model domain (NX x NY x NZ) for each water quality variable (NOSYS) (Real)

RCAFICSED (internal RCA file number 16)

Record 1: CTEMP, CPOP, CPON, CPOC, CPOS, PO4T2, NH4T2, NO3T2, H2ST2, SIT2, BNTHSTRS, PO4T1, NH4T1, NO3T1, SIT1, H2ST1, CH4T1, CH4T2, SO4T2, PO41, NH41, NO31, H2S1, SI1, O2O, SOD, DDO, BFORMAXS, ISWBNTHS

where "array" are arrays (NX x NY x NZ), as listed above, containing the sediment bed concentrations, benthic stress, SOD, overlying water column, depth of aerobic layer for each sediment model segment (Real)

RCA Flux Balance/Mass Balance Files - RCAFMB and RCAMBSED

Should the user chose to perform flux balance/mass balance computations for an RCA simulation, the requested information will be written to RCAFMB for the water column and RCAMBSED for the sediment nutrient flux model if it is used in the model computations.

RCAFMB (internal RCA file number 17)

Records 1 -> TIME,SYSMASS,SYSLOADS,FLXMB,FLYMB

where TIME is the time at which the flux balance/mass balance computations are being written,
SYSMASS a vector (NOSYS) containing the total mass for each system in the model(Real).

SYSLOADS	an array (4,NOSYS) containing the total mass loading rate (g/day) for each system in the model. These loading rates are point source, nonpoint source, fall-line, and atmospheric, respectively.
FLXMB	an array (NX x NY) containing the depth-integrated flux terms (mg/day) for each X-interface in the model
FLYMB	an array (NX x NY) containing the depth-integrated flux terms (mg/day) for each Y-interface in the model

Record 1 contains the mass balance/flux balance terms at the start of the mass balance/flux balance computations, while records 2 and forward contain the same computations written at an interval selected by the user.

RCAFMBSED (internal RCA file number 18)

Records 1 -> TIME, TOTORGP, TOTORGN, TOTORGC, TOTBSI, TOTPO4, TOTNH4, TOTNO3, TOTSI, TOTH2S, TOTCH4, TOTSO4, JPOP, JPON, JPOC, JBSI, JPO4SS, JSISS, BURIALORGP, BURIALORGN, BURIALORGC, BURIALBSI, BURIALPO4, BURIALNH4, BURIALNO3, BURIALSI, BURIALH2S, BURIALCH4, BURIALSO4, TOTJPO4, TOTJN4, TOTNHO3, TOTHN2, TOTJSI, TOTJH2S, TOTJCH4AQ, TOTHCH4G, TOTSOD

where TIME	is the time at which the flux balance/mass balance computations are being written,
"arrays"	arrays (NX x NY) containing the total mass or flux rate, as listed above, for each relevant system of the sediment flux model (Real).

Record 1 contains the mass balance/flux balance terms at the start of the mass balance/flux balance computations, while records 2 and forward contain the same computations written at an interval selected by the user.

Internal RCA Files

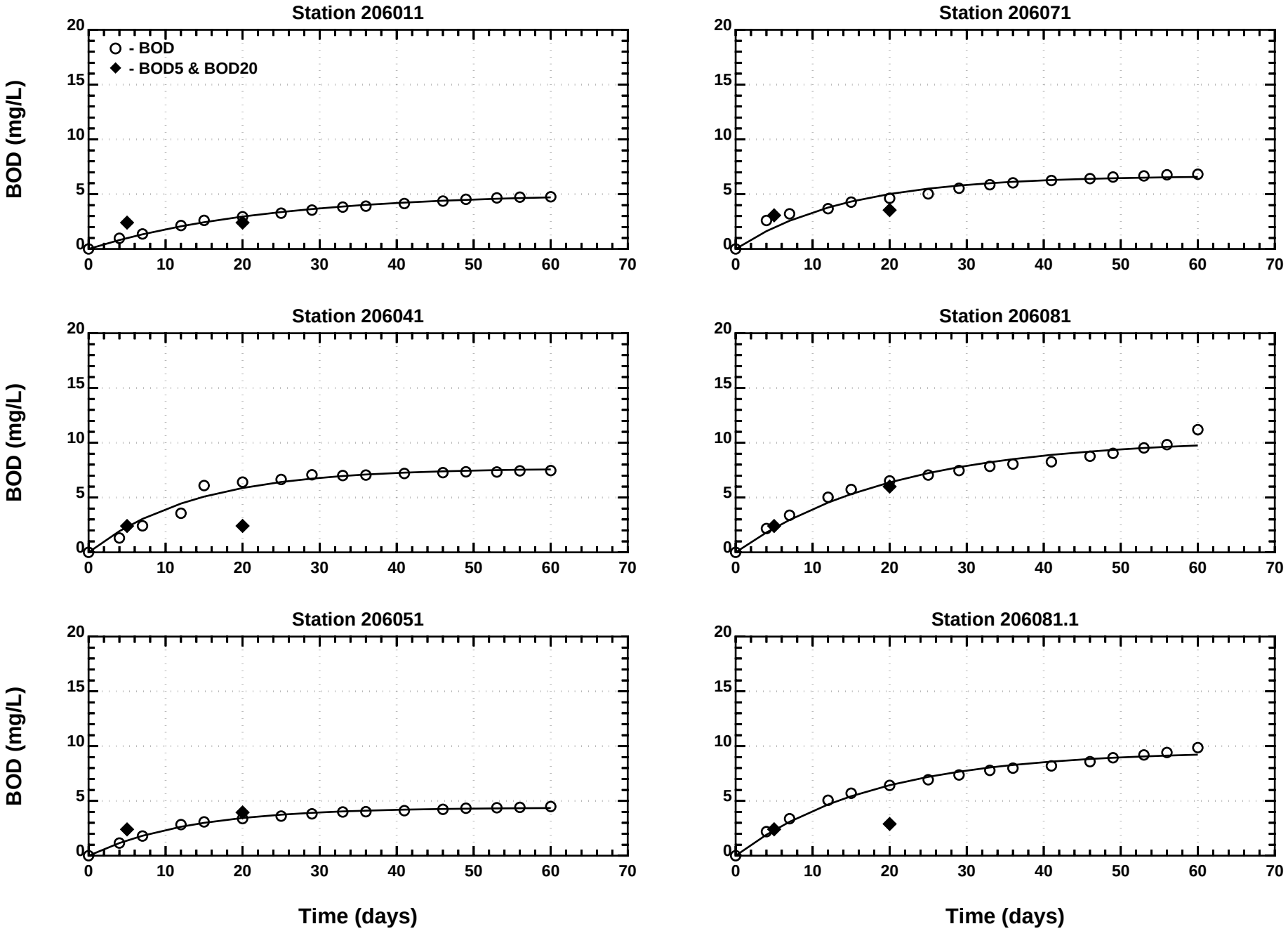
In addition to the files listed about, RCA utilizes a number of input files and/or temporary files for saving intermediate computations. The following file numbers are reserved by RCA for use as input files:

30 - gcm_geom, wet_grid, and the hydrodynamic transport file(s) - HYDFILNA
31 - the diffuser file (DIFFILNA) generated by the hydrodynamic model
32 - the boundary condition file (BCFILNA)
33 - the point source file (PSFILNA)
34 - the nonpoint source file (NPSFILNA)
35 - the fall-line source file (FLFILNA)
36 - the atmospheric source file (ATMFILNA)
37 - the parameters, constants, and time-variable functions input file (PCFILNA)
38 - the initial conditions file (ICFILNA).

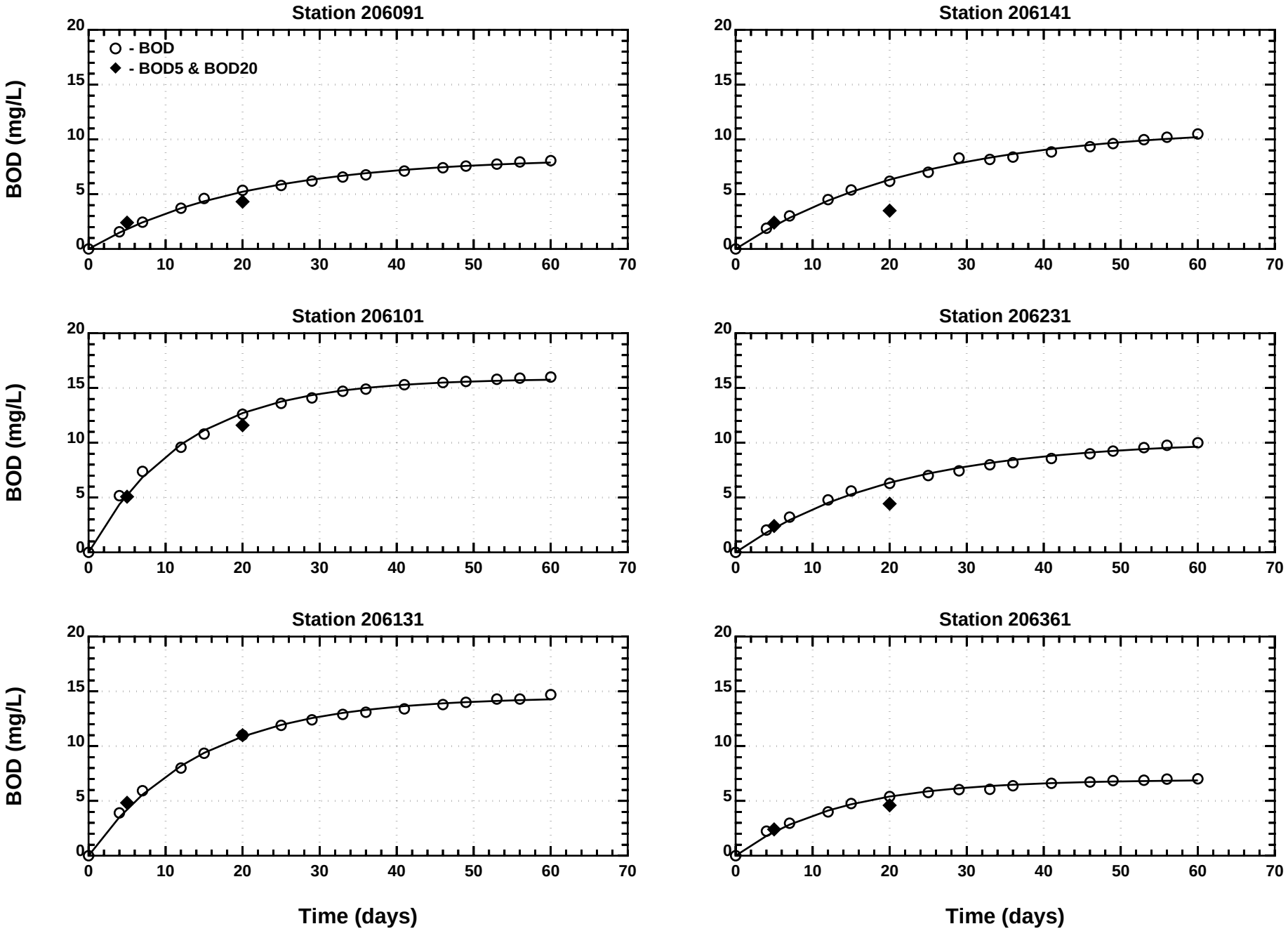
When developing new kinetic subroutines, the model develop should be aware of the file numbers already "assigned" by RCA and should be careful not to assign "new" files to existing file numbers (i.e., 10-18 and 30-38).

APPENDIX 8

LTBOD RESULTS
FOR RIVER SITES



Murderkill River LTBOD Data (4/24/2007)



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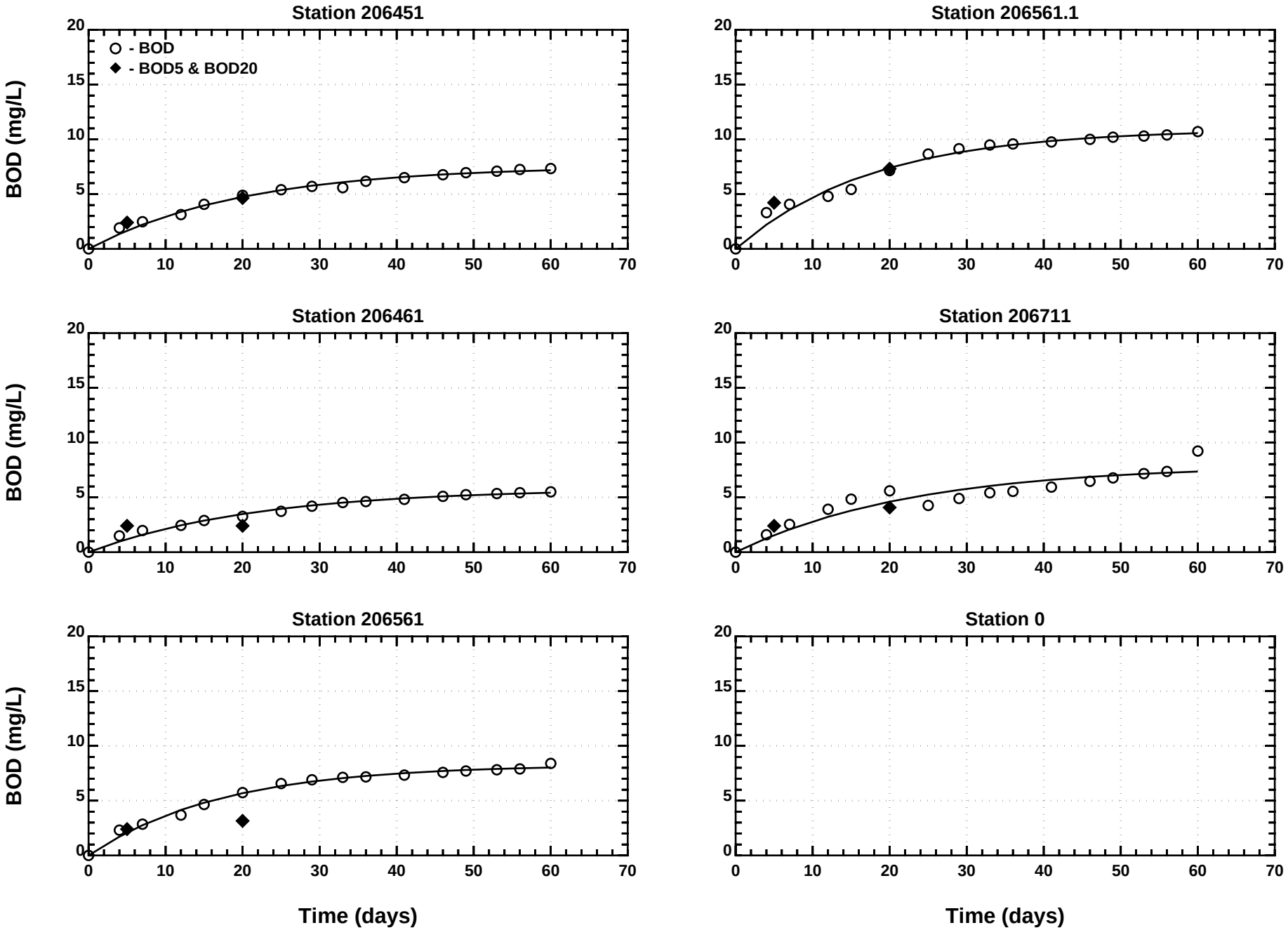
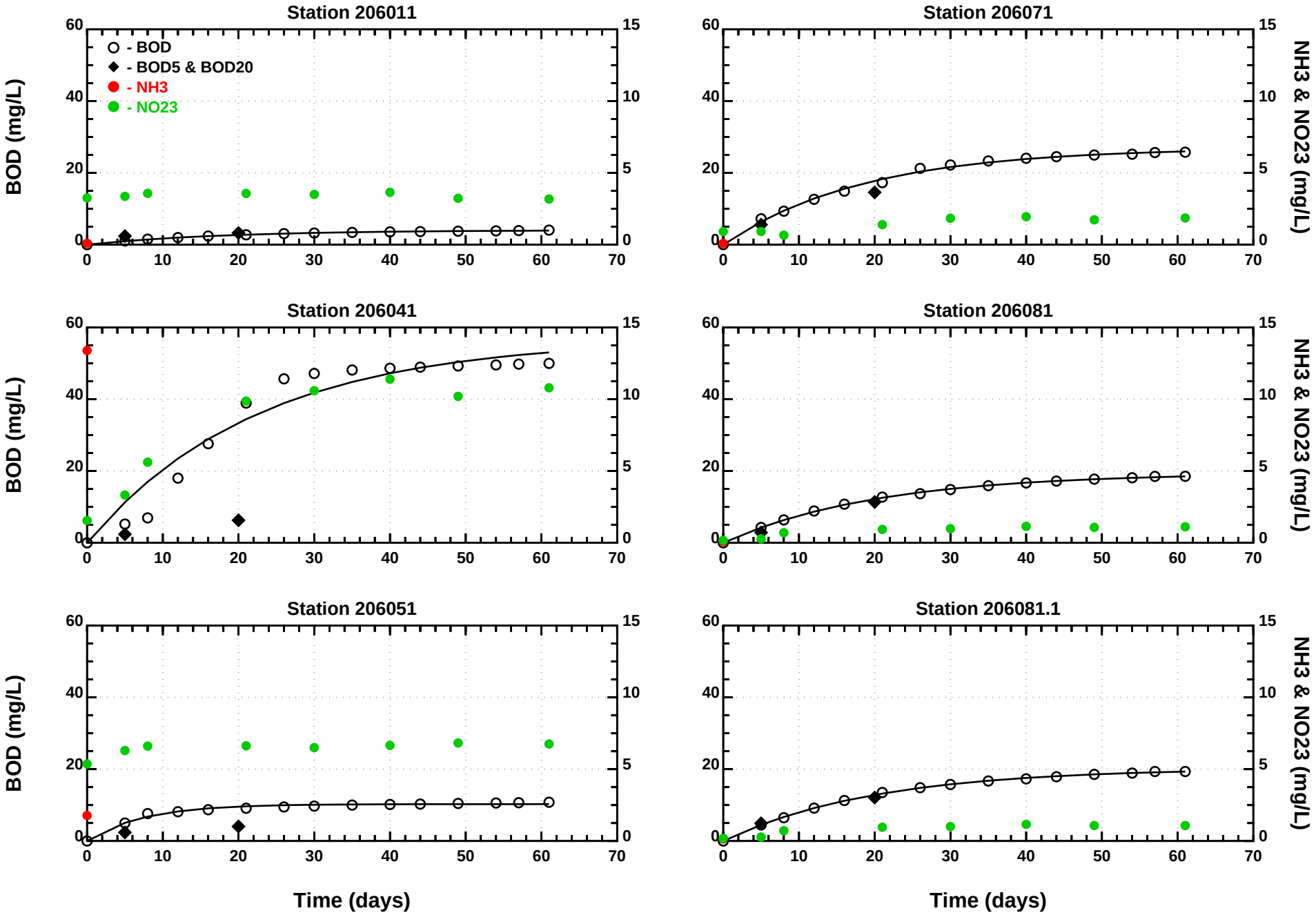
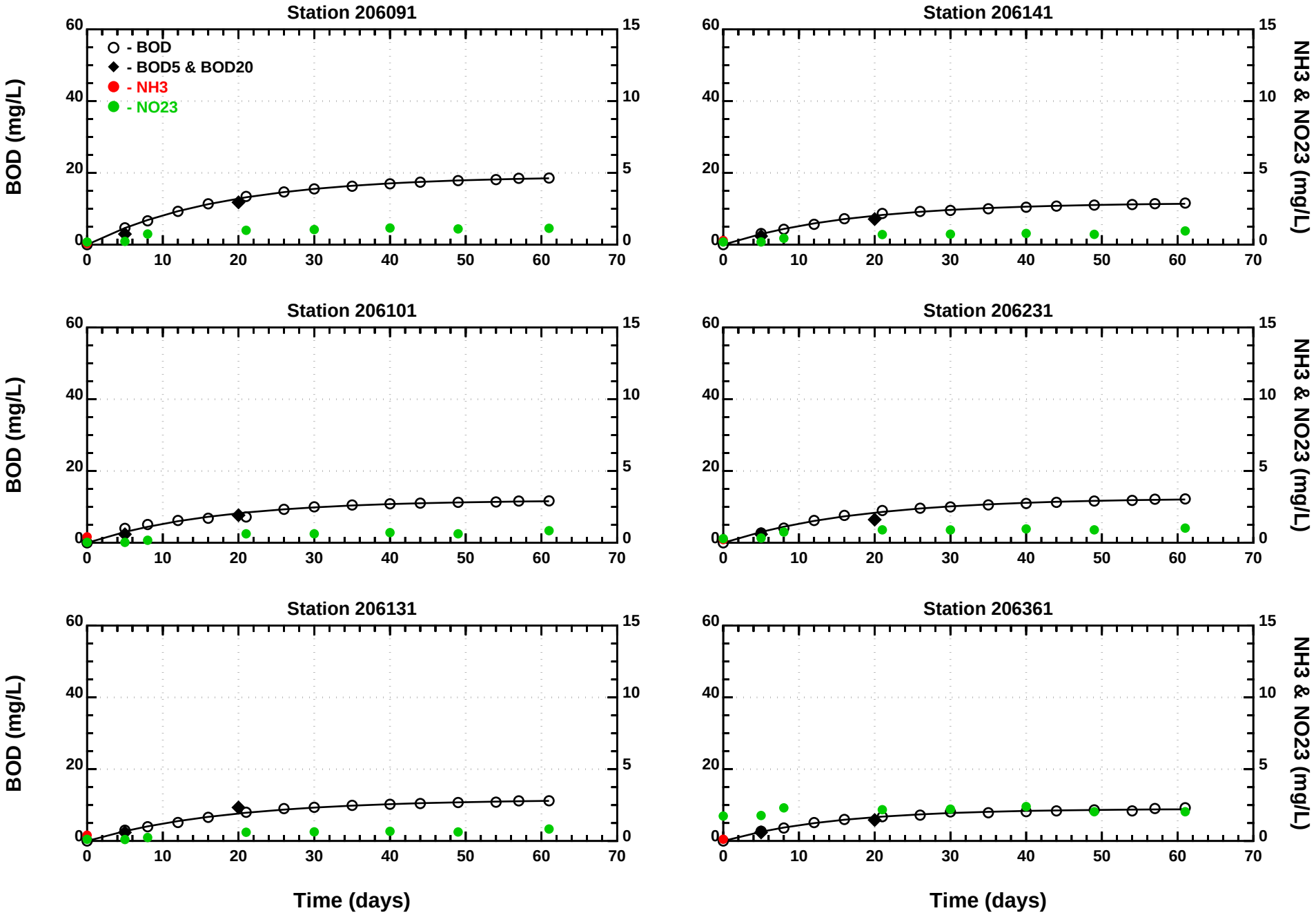


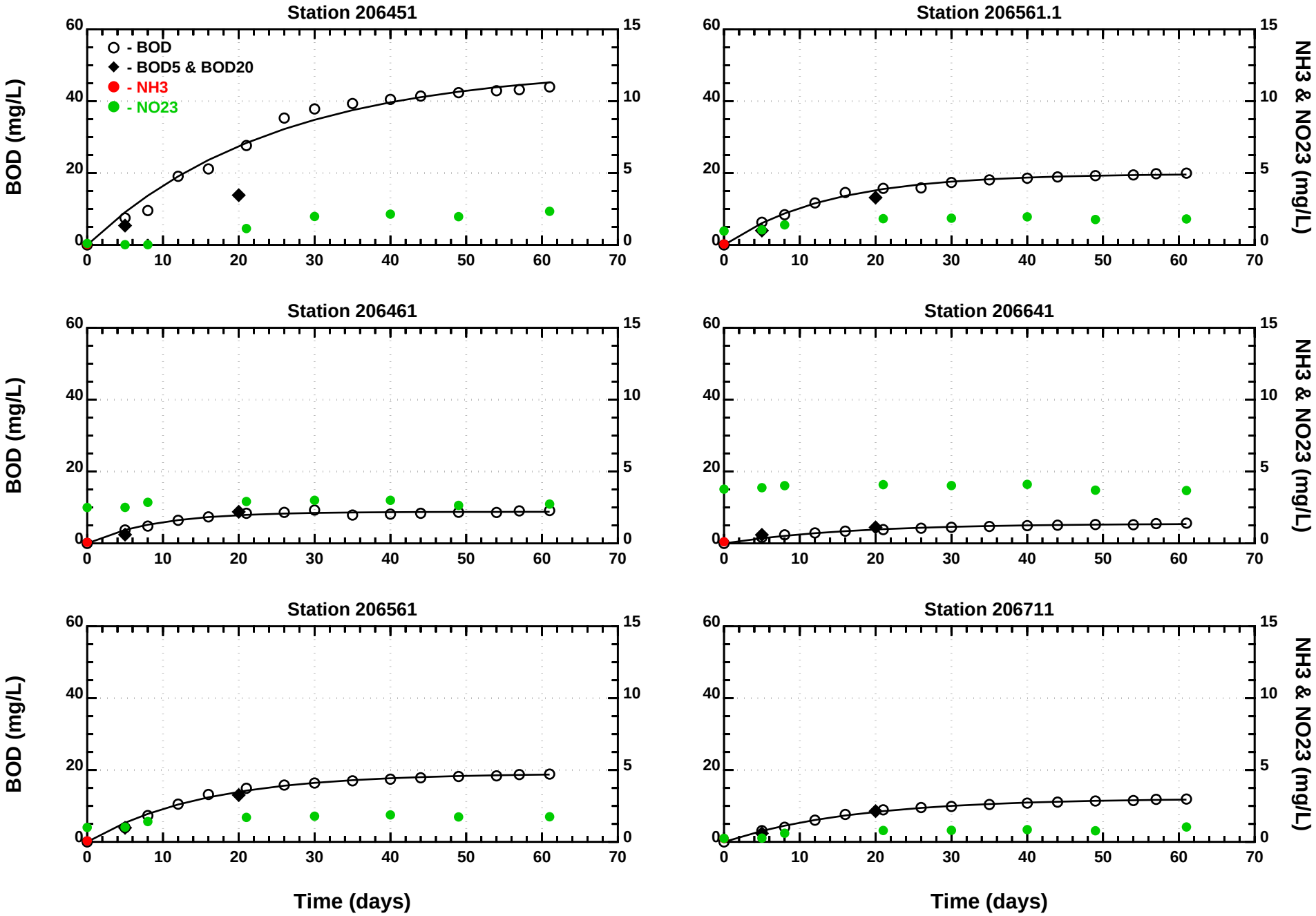
Murderkill River LTBOD Data (4/24/2007)



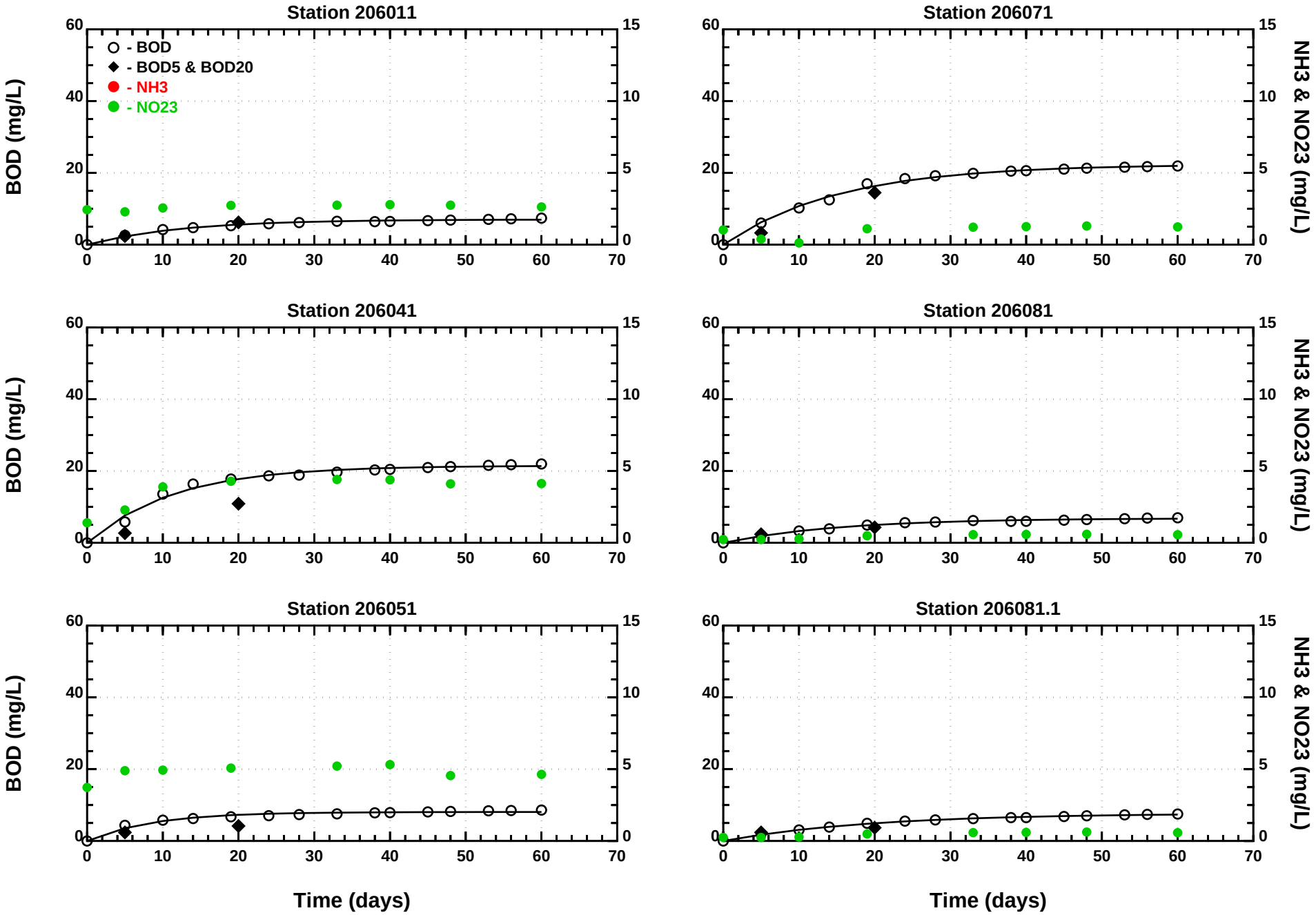
Murderkill River LTBOD Data (7/30/2007)



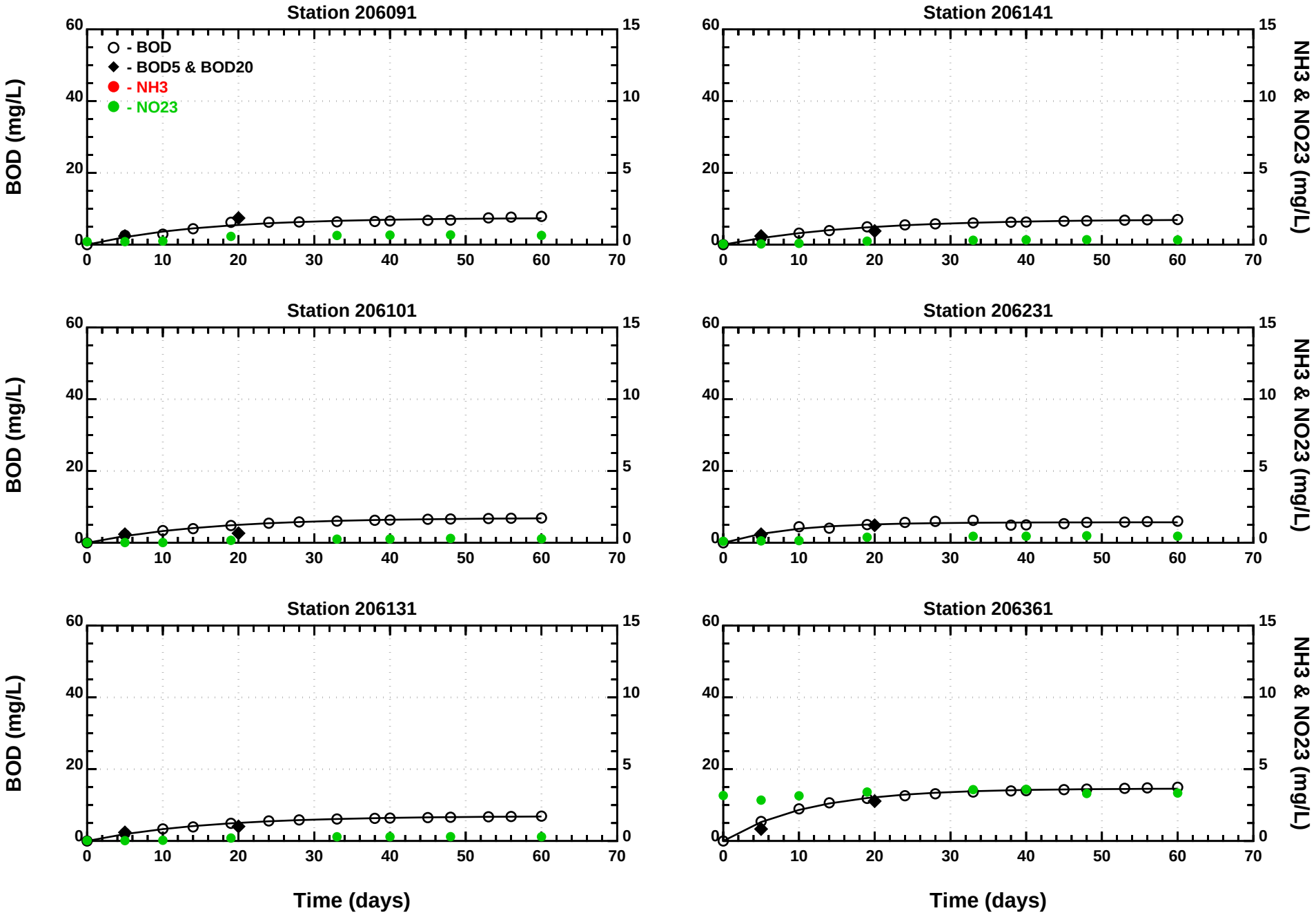
Murderkill River LTBOD Data (7/30/2007)



Murderkill River LTBOD Data (7/30/2007)



Murderkill River LTBOD Data (10/10/2007)



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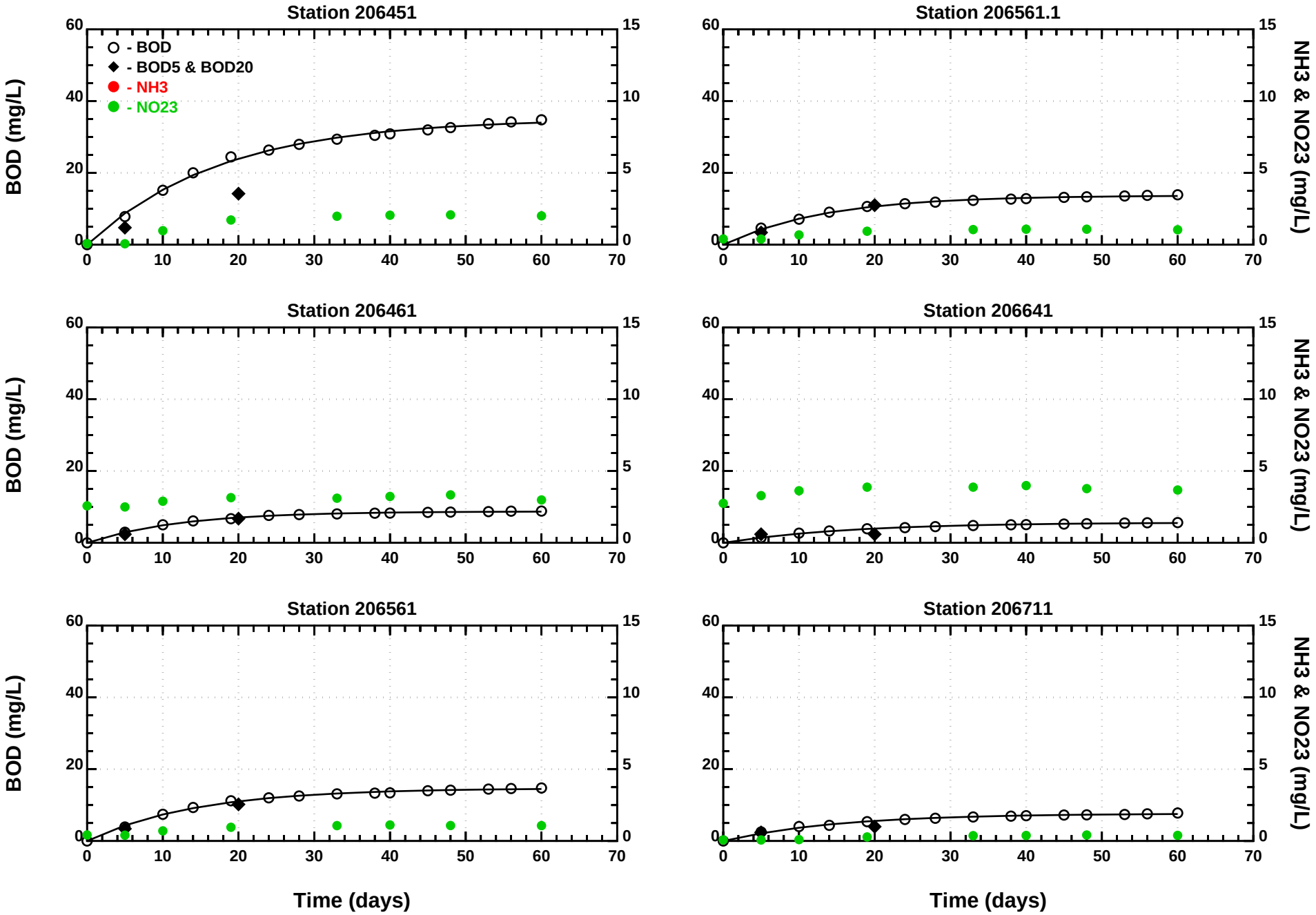

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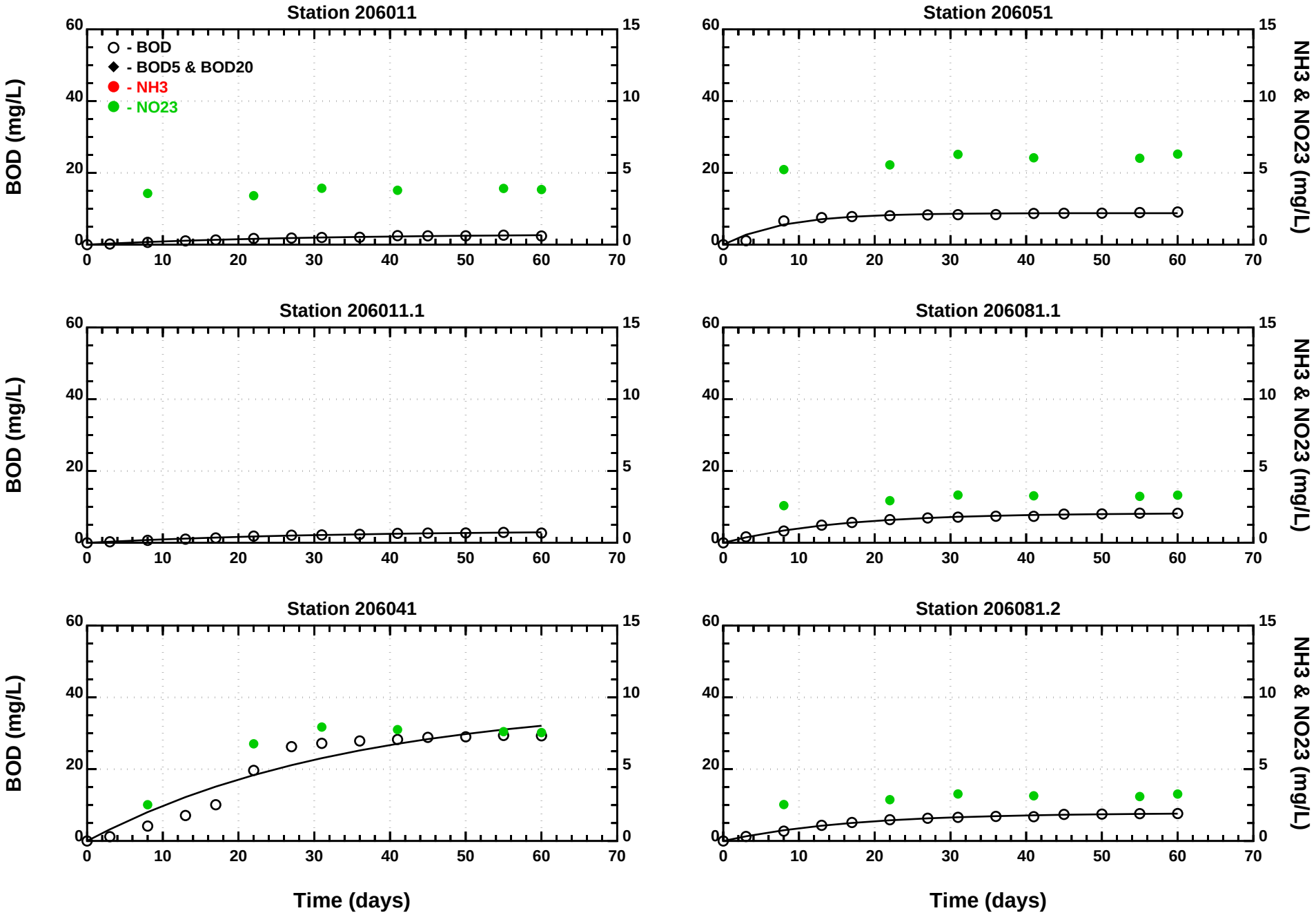
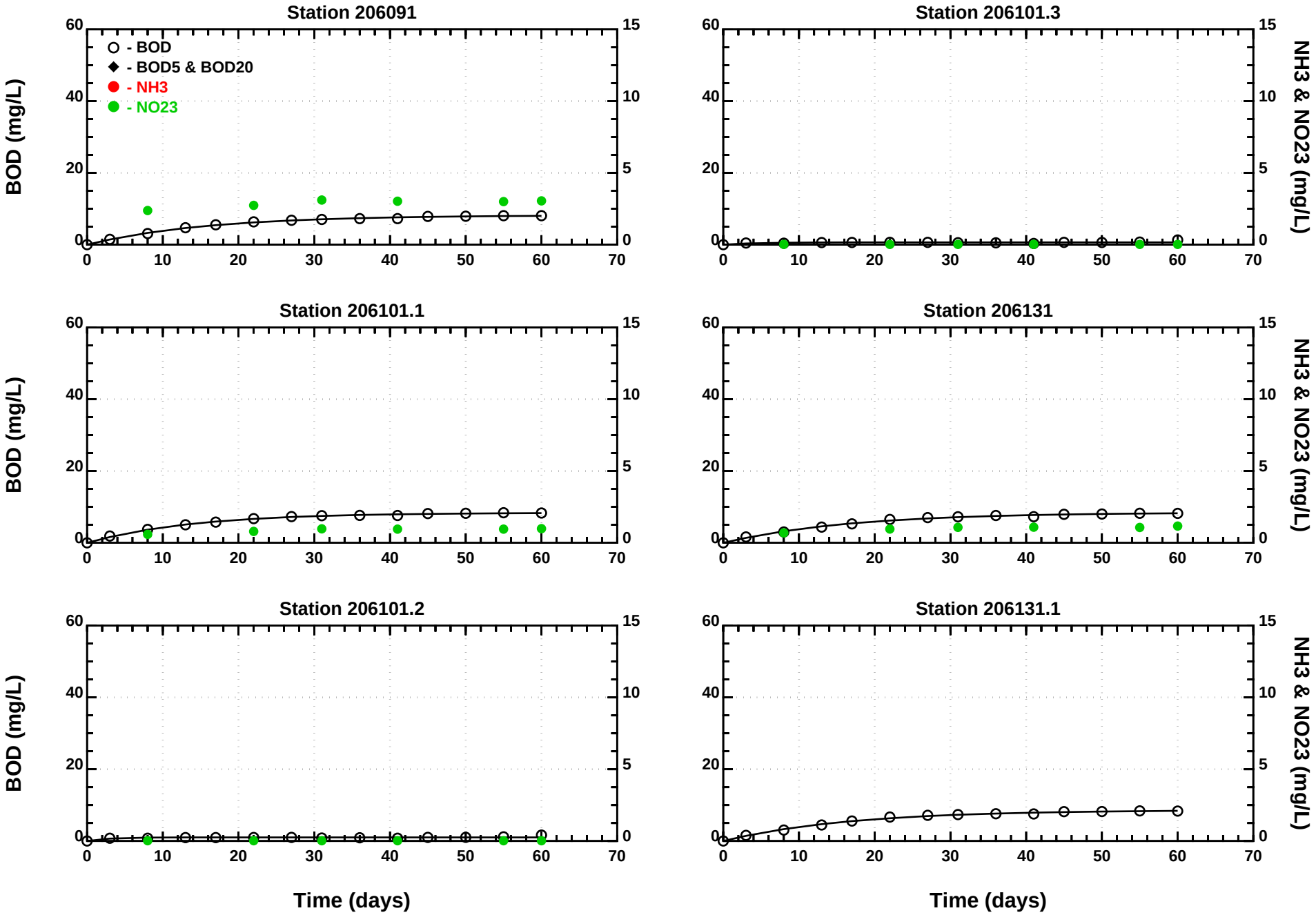


Murderkill River LTBOD Data (1/29/2008)



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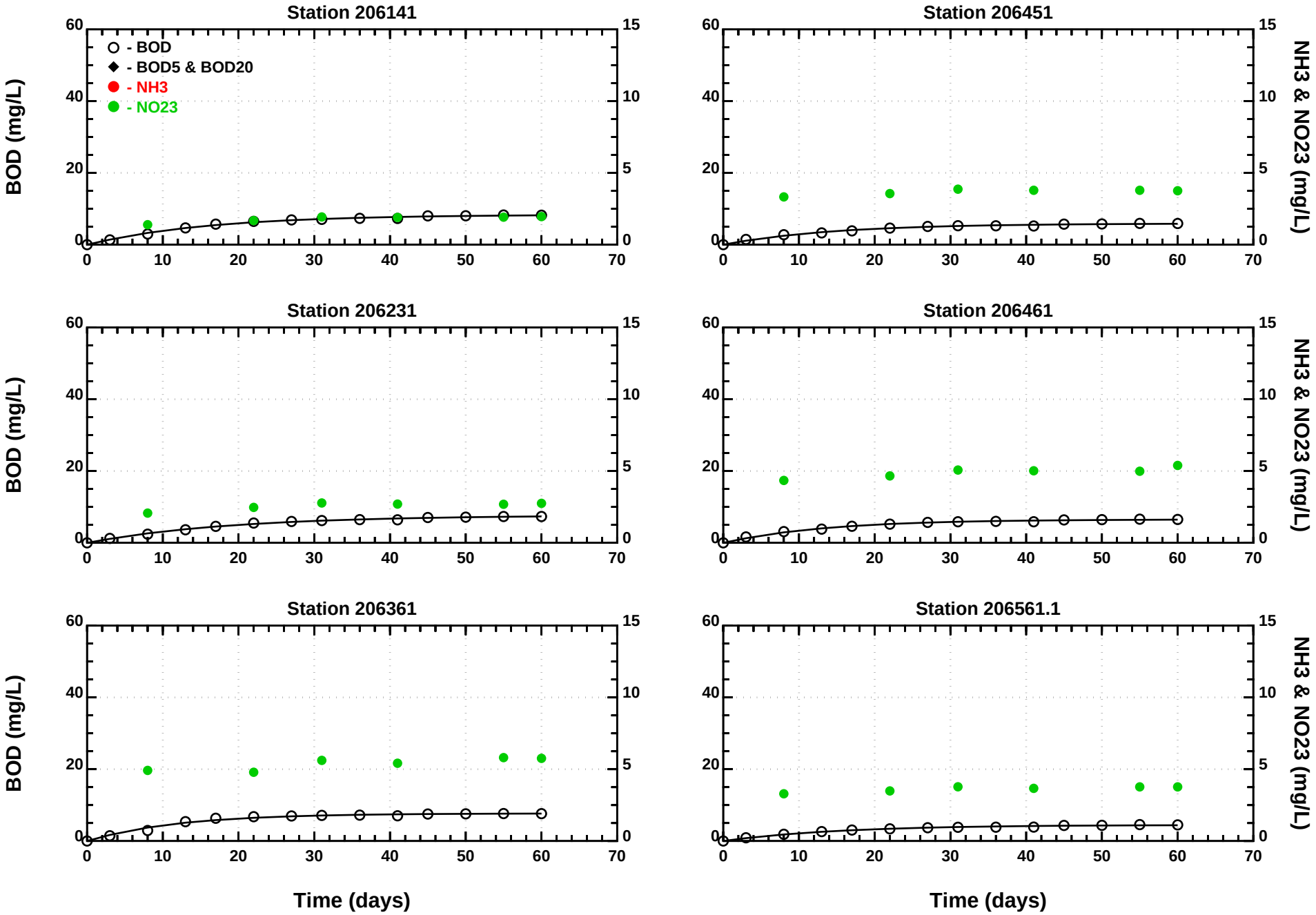

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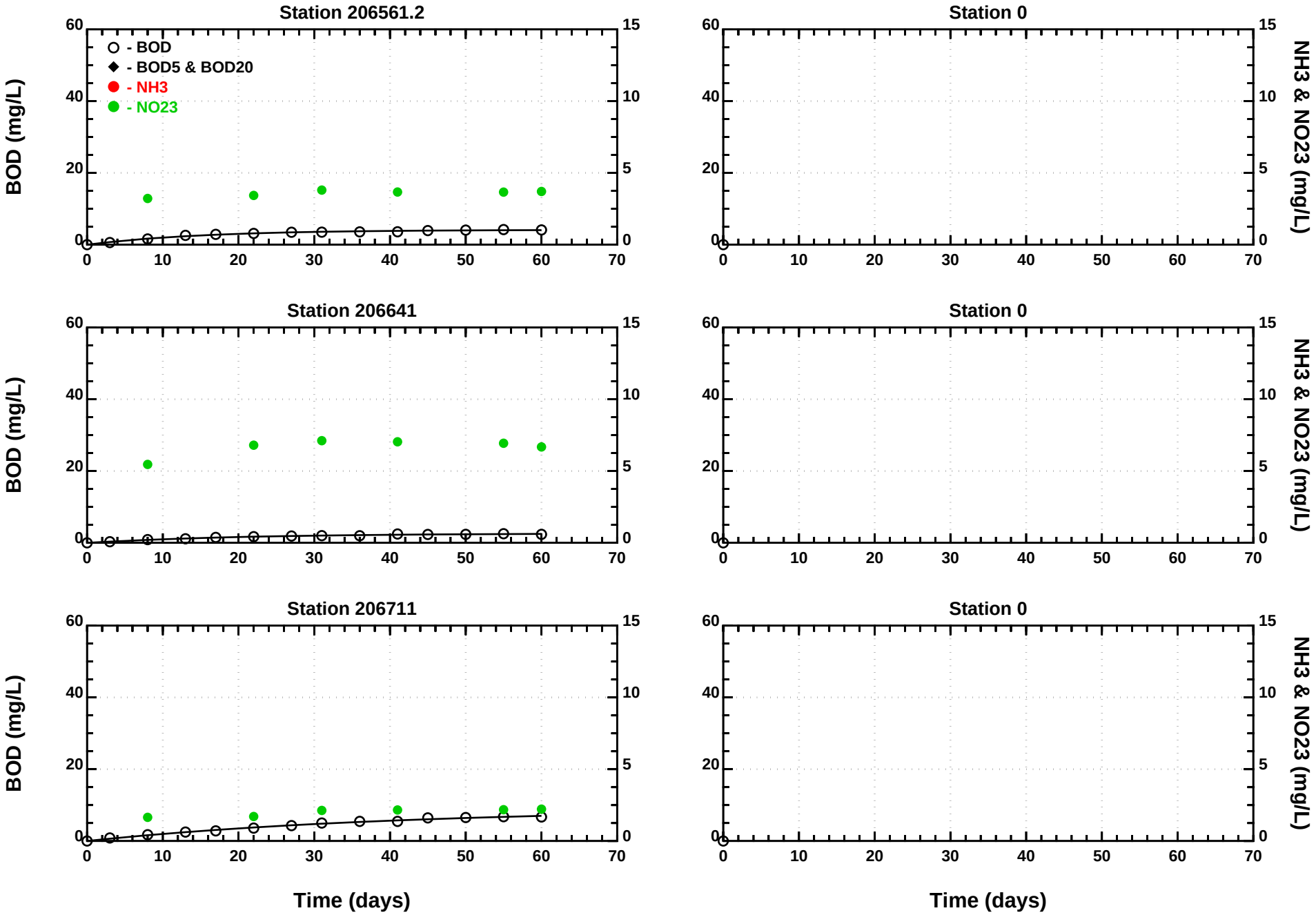
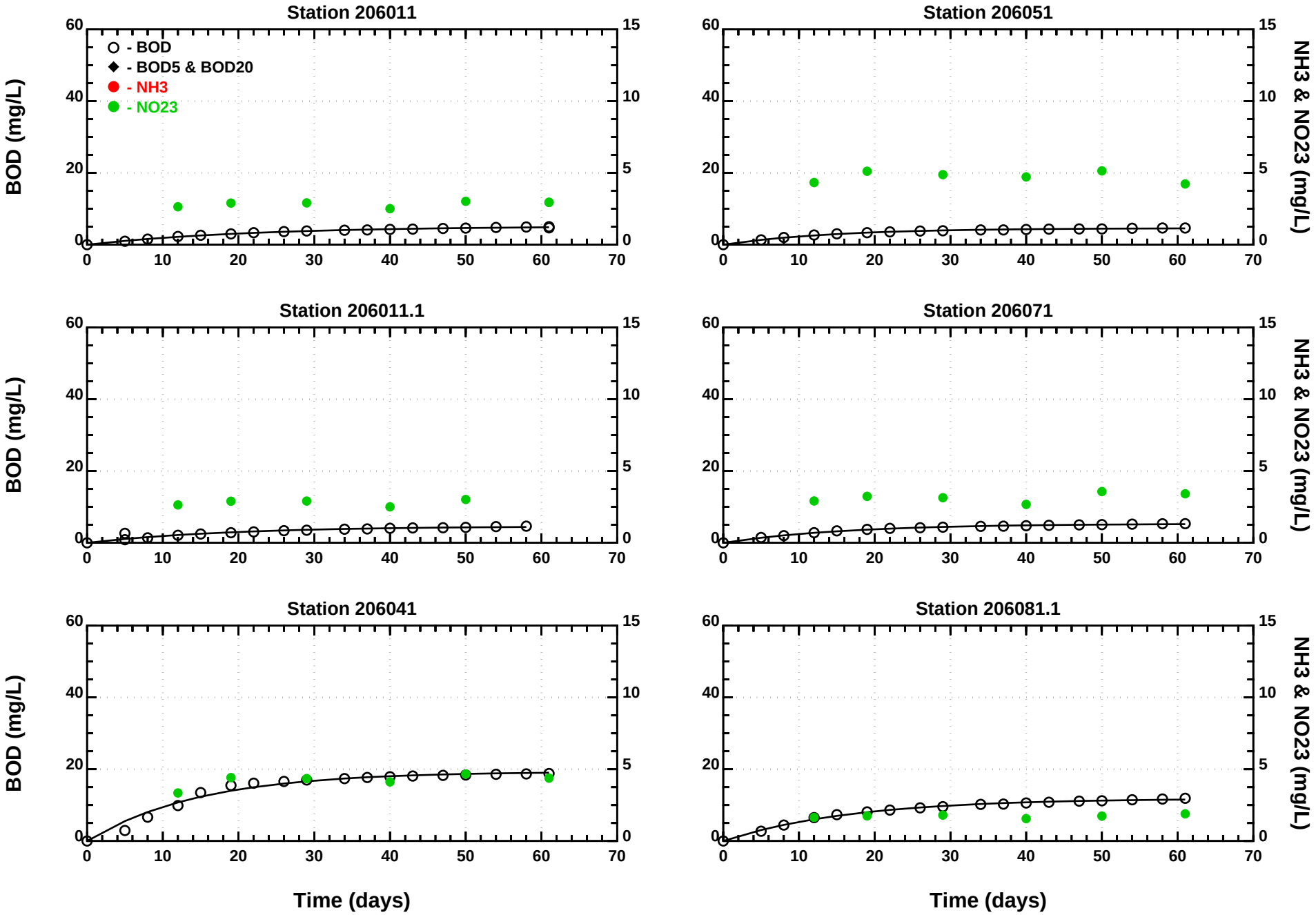
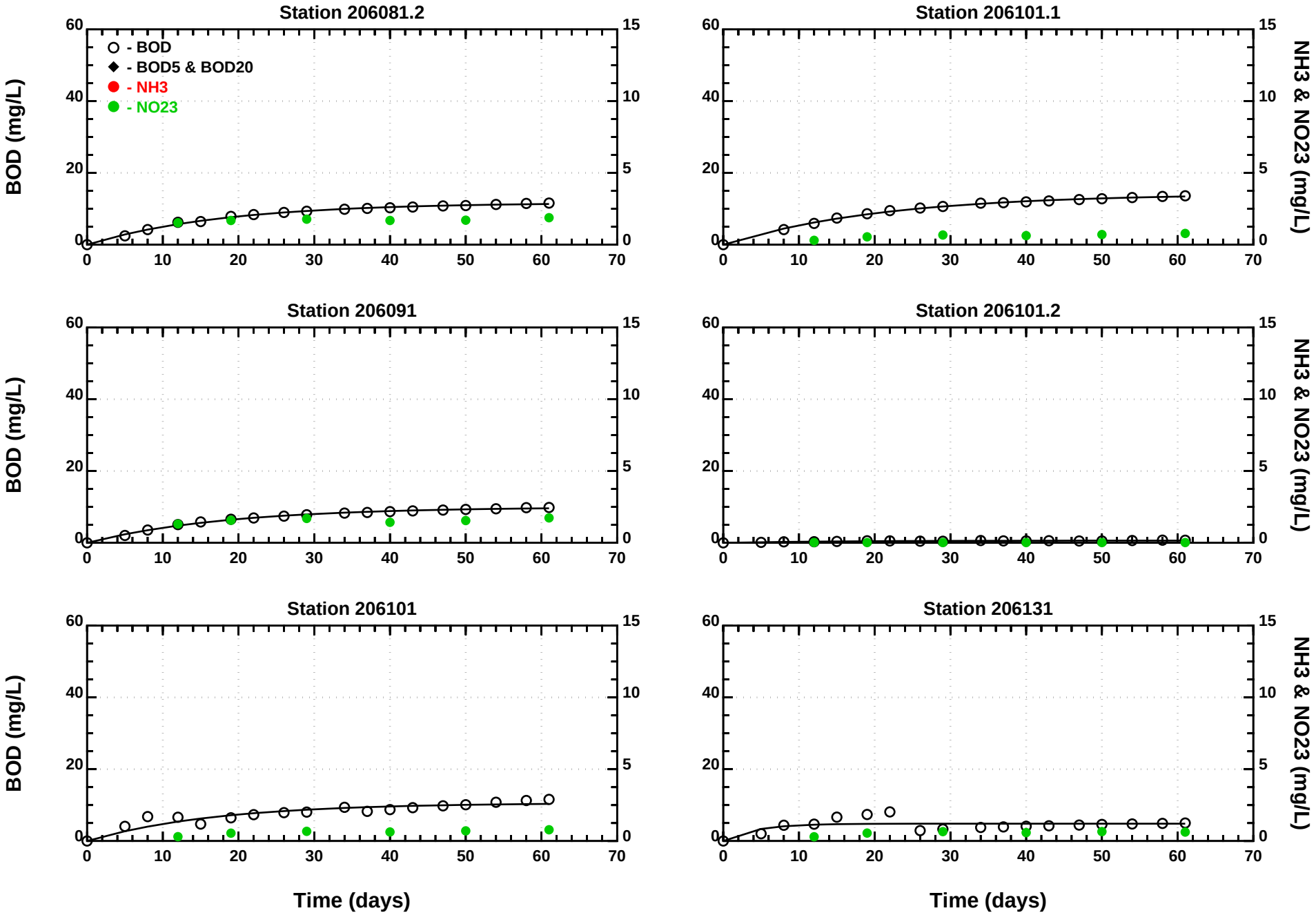


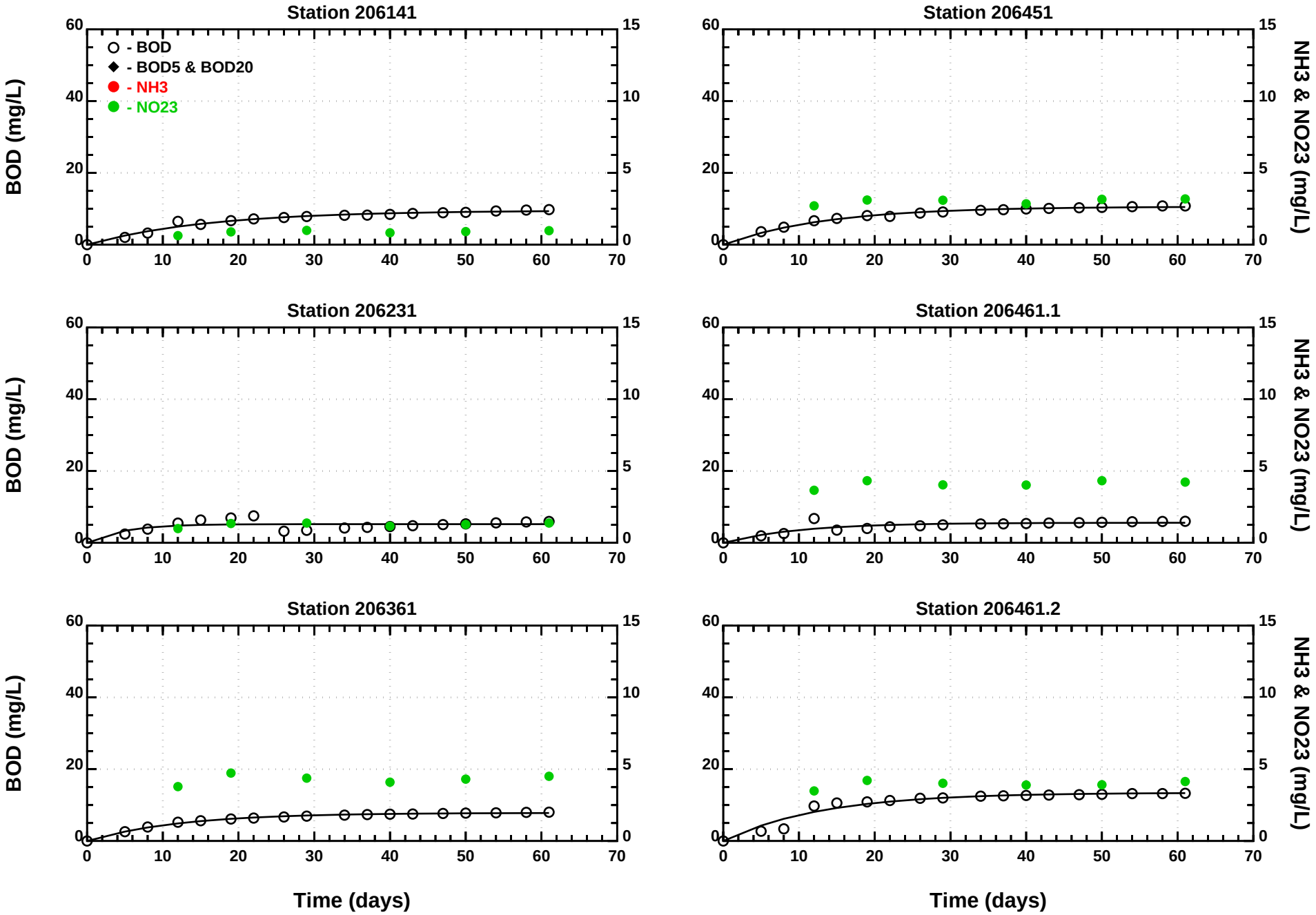
Murderkill River LTBOD Data (1/29/2008)



Murderkill River LTBOD Data (4/21/2008)



Murderkill River LTBOD Data (4/21/2008)



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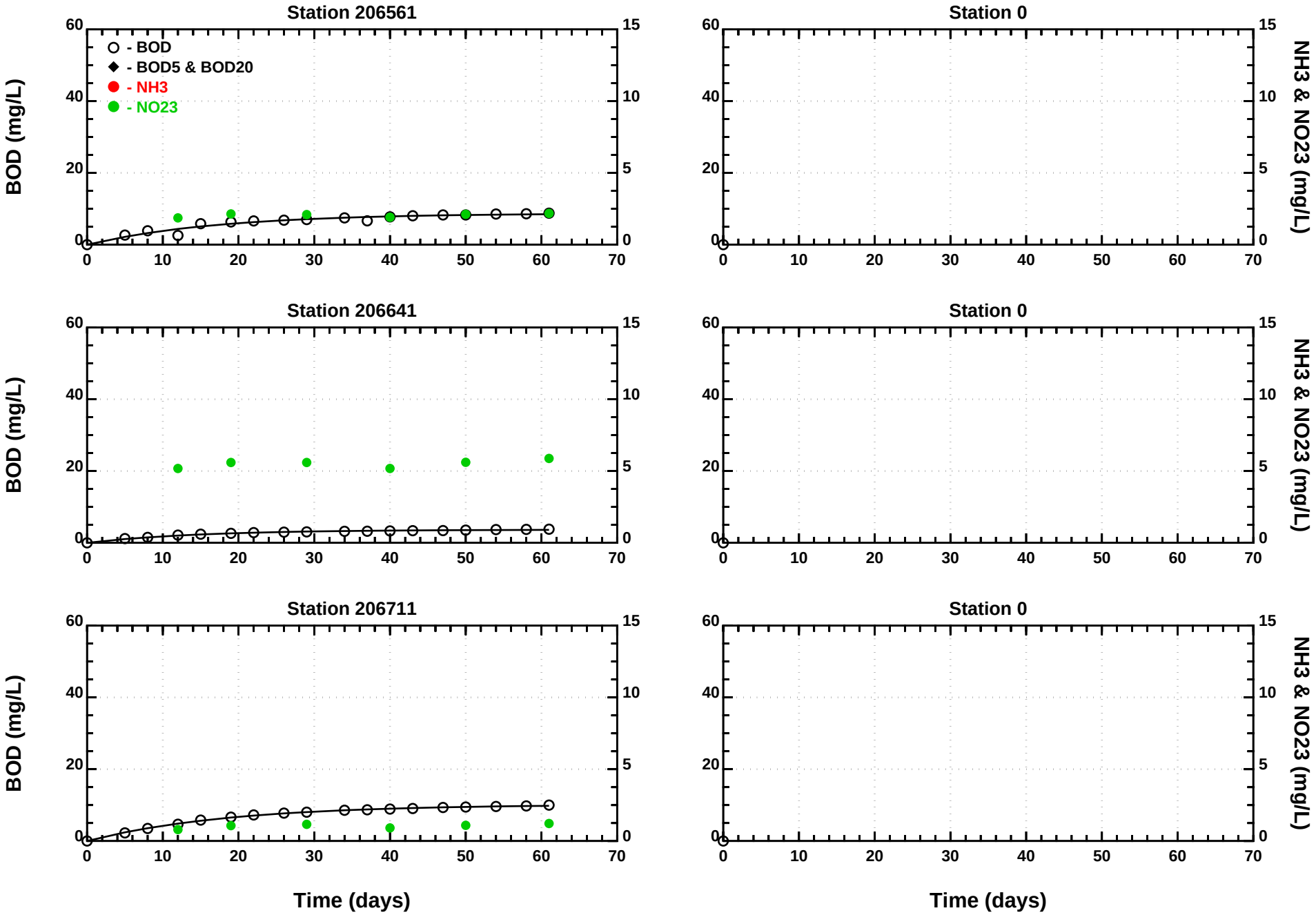

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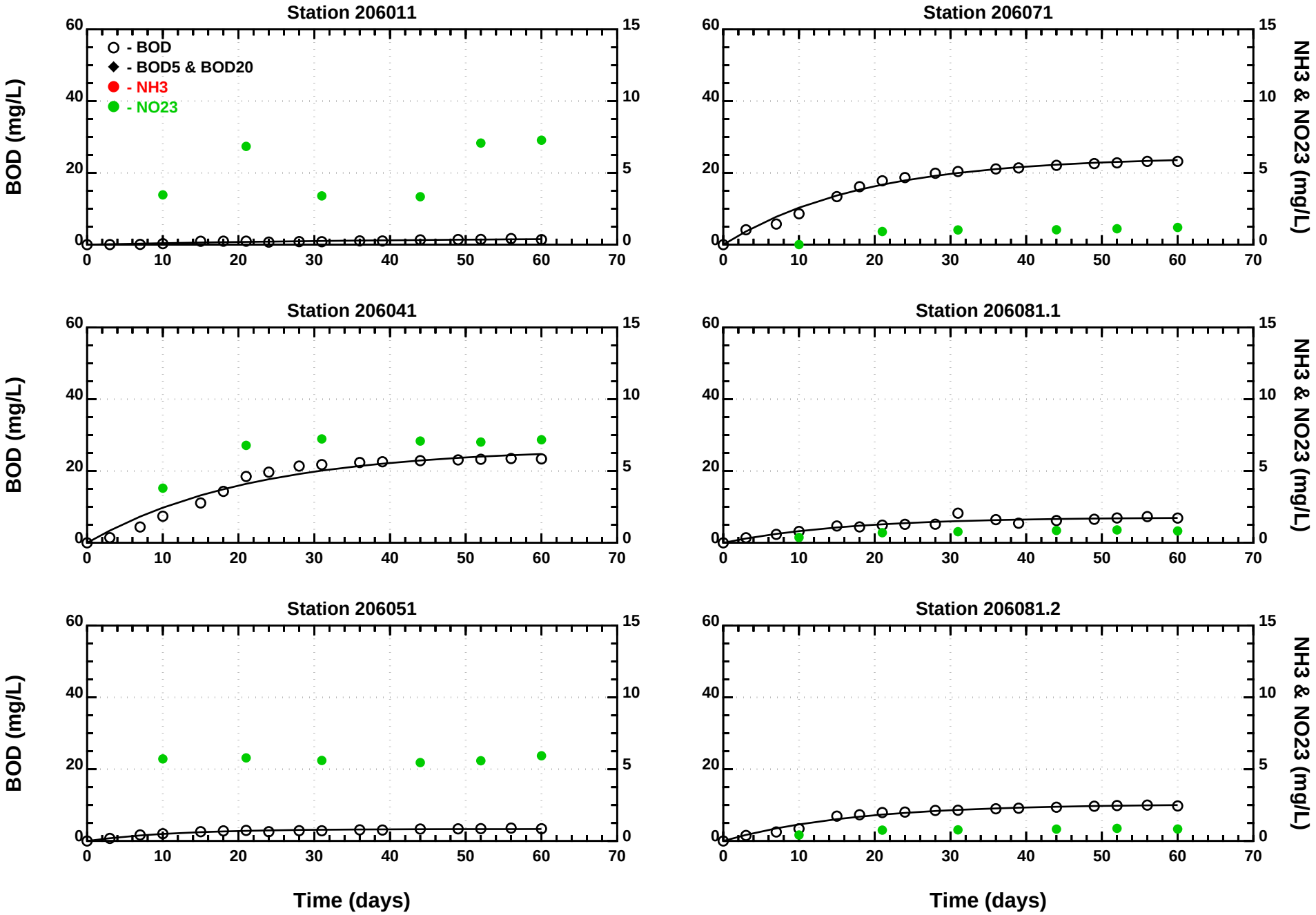
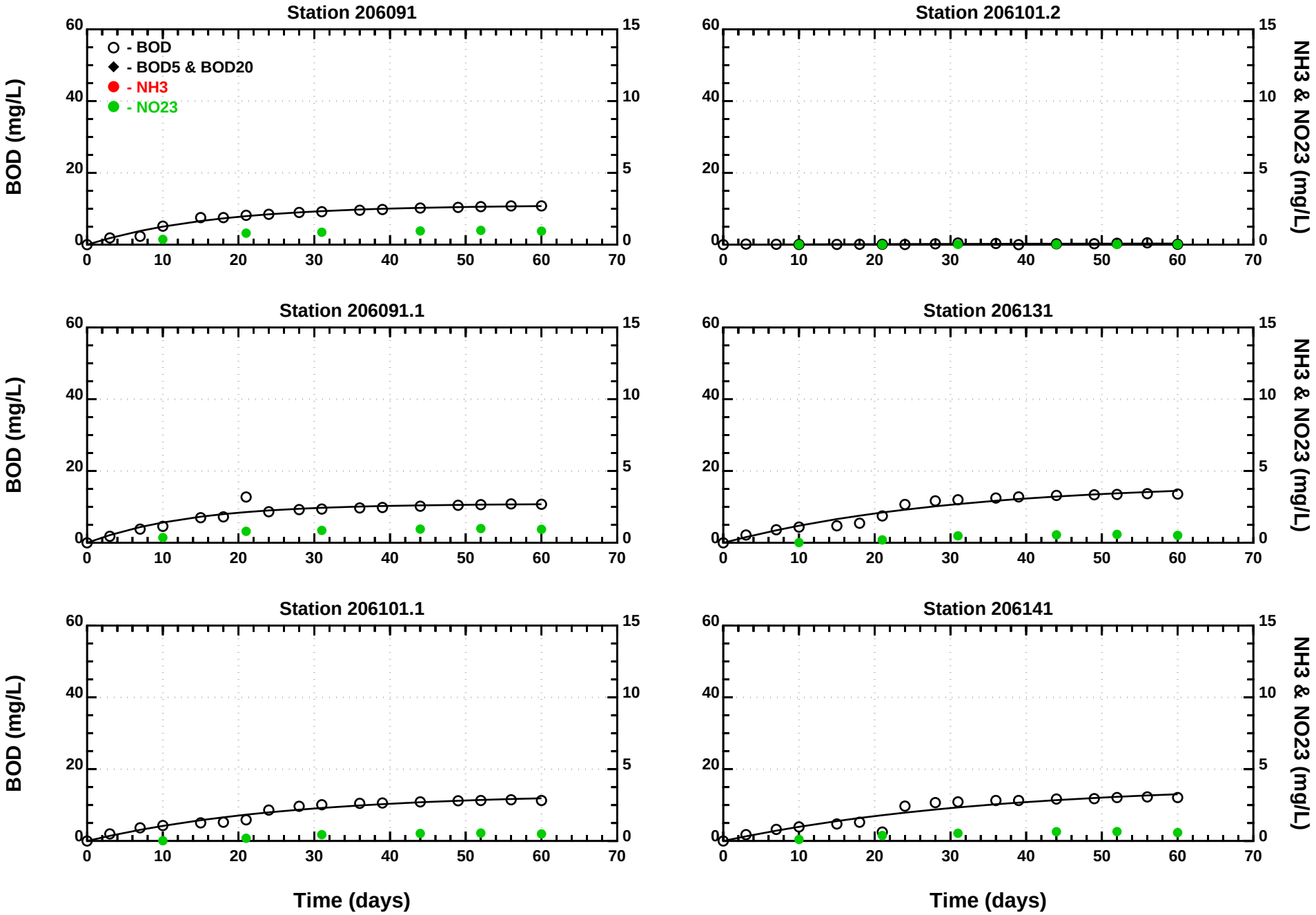
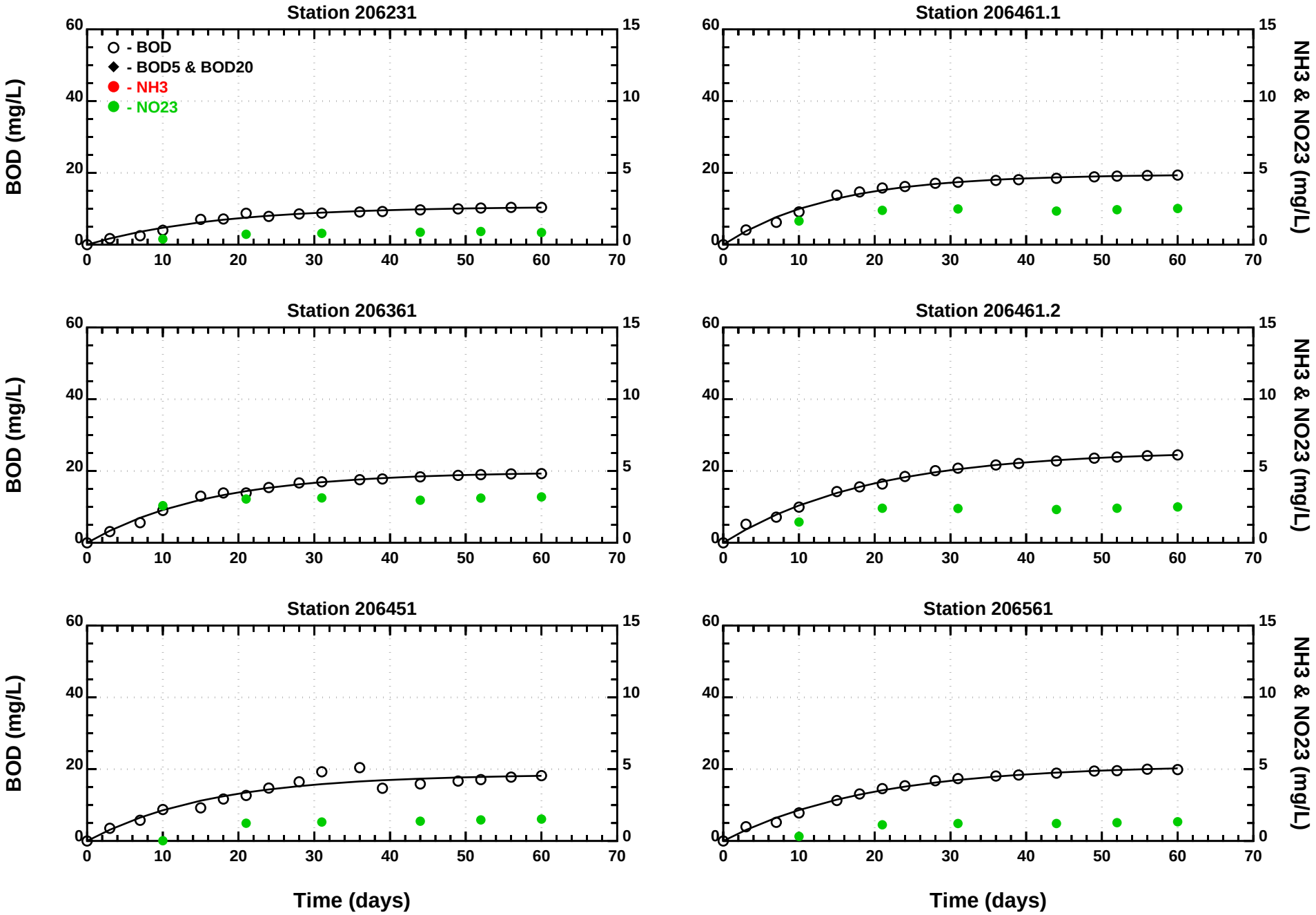


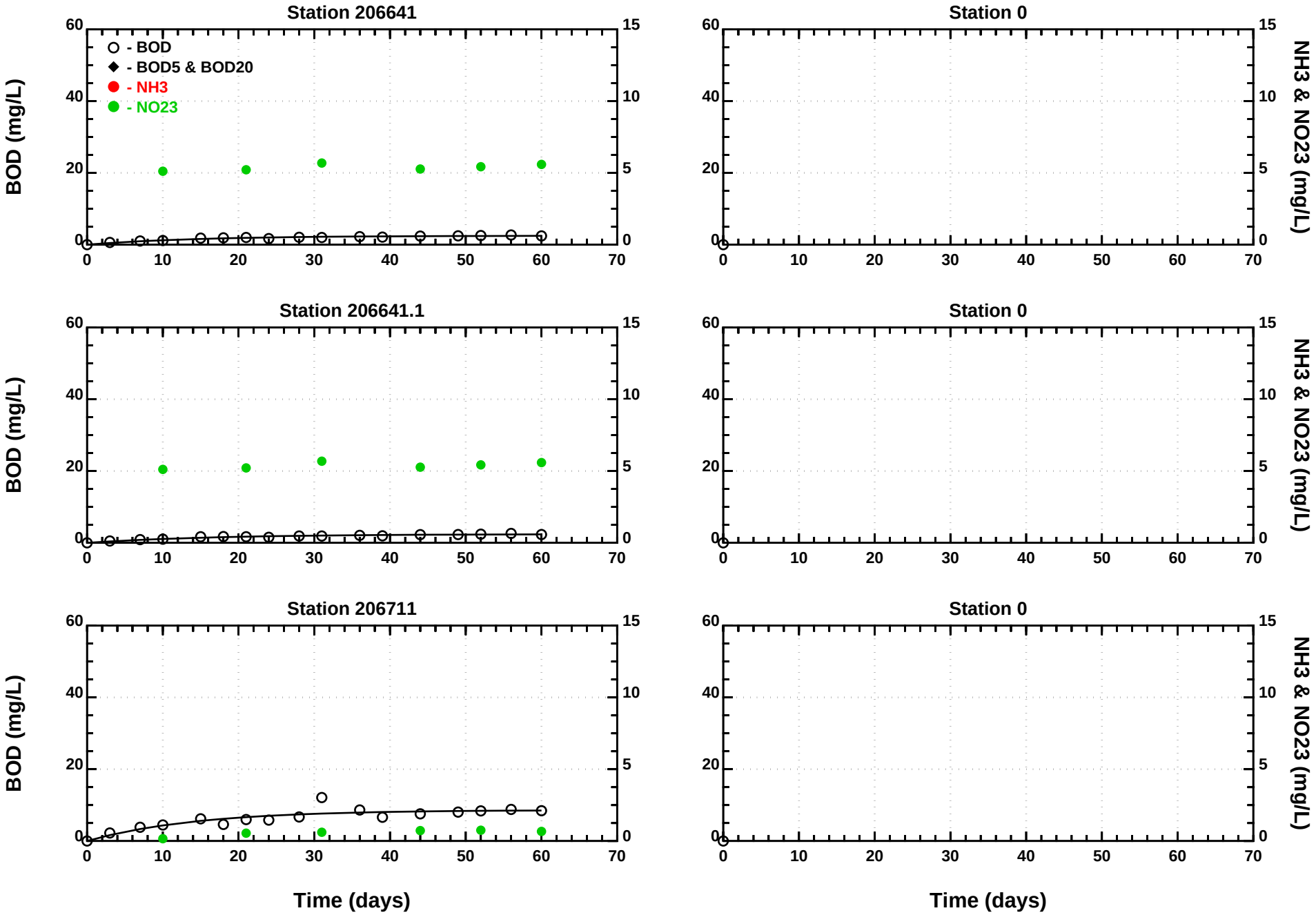
Murderkill River LTBOD Data (7/28/2008)



Murderkill River LTBOD Data (7/28/2008)



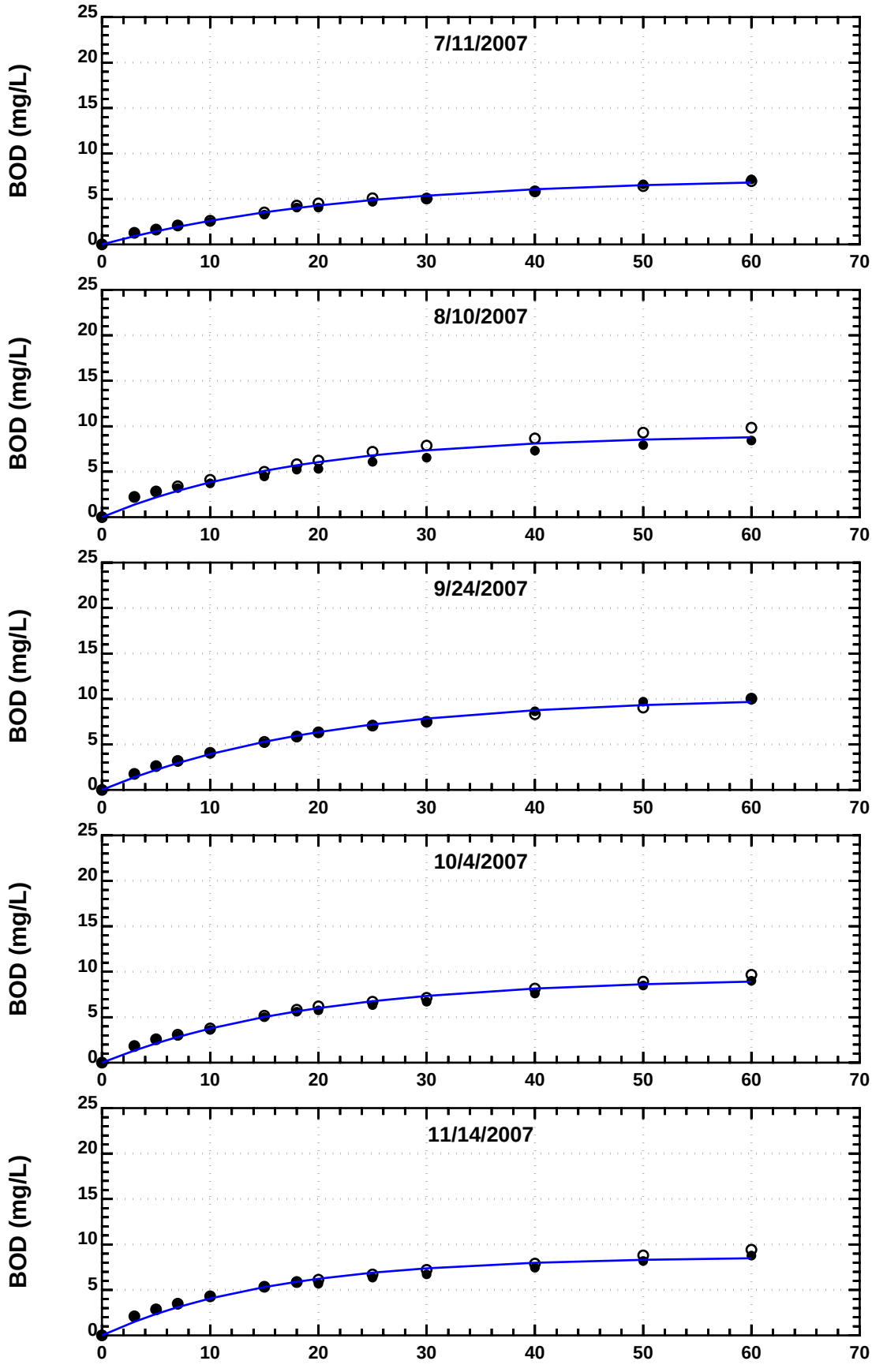
Murderkill River LTBOD Data (7/28/2008)



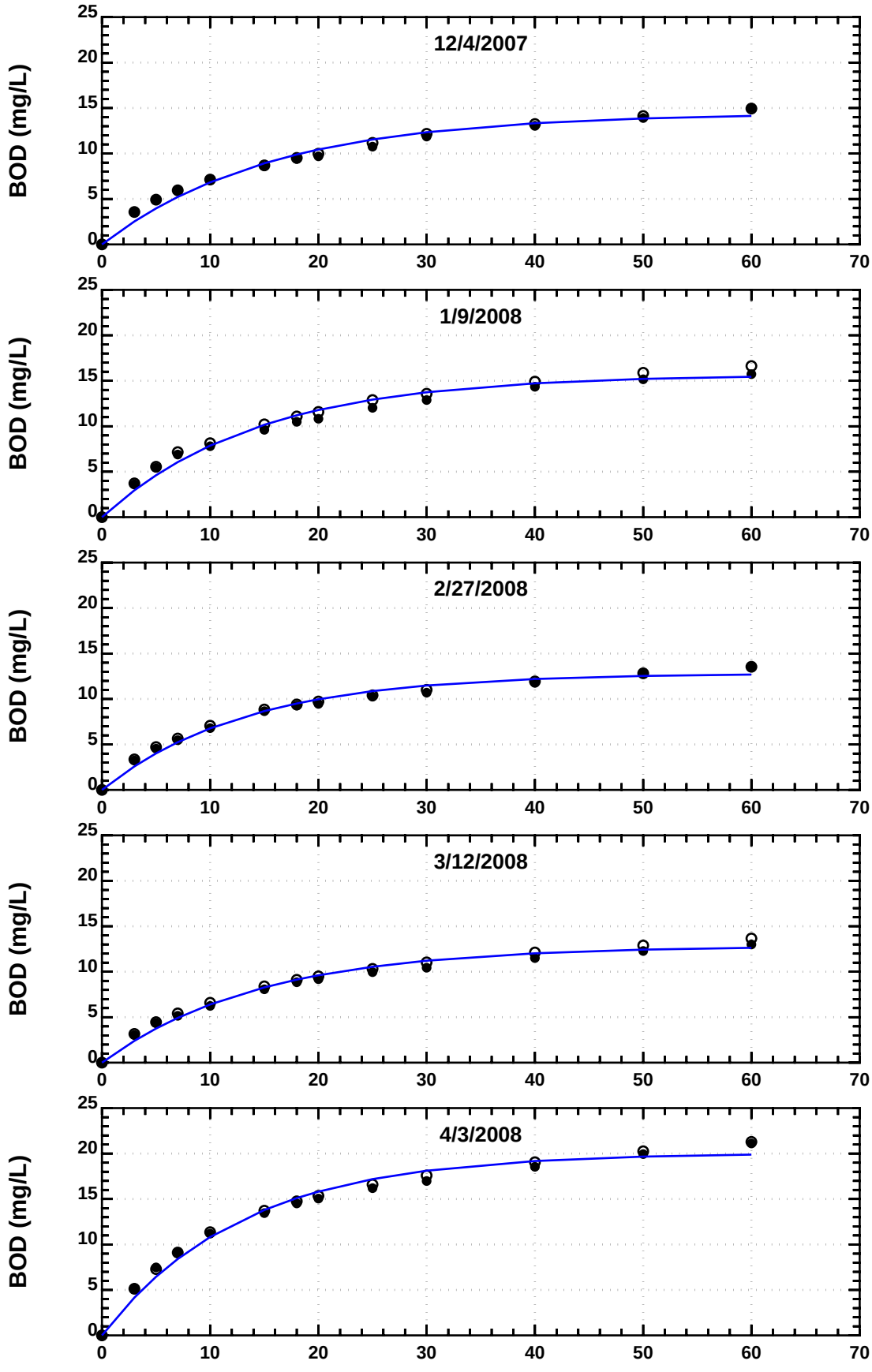
Murderkill River LTBOD Data (7/28/2008)

APPENDIX 9

LTBOD RESULTS
FOR KCRWTF DISCHARGE



Kent County WWTP Effluent LTBOD Data



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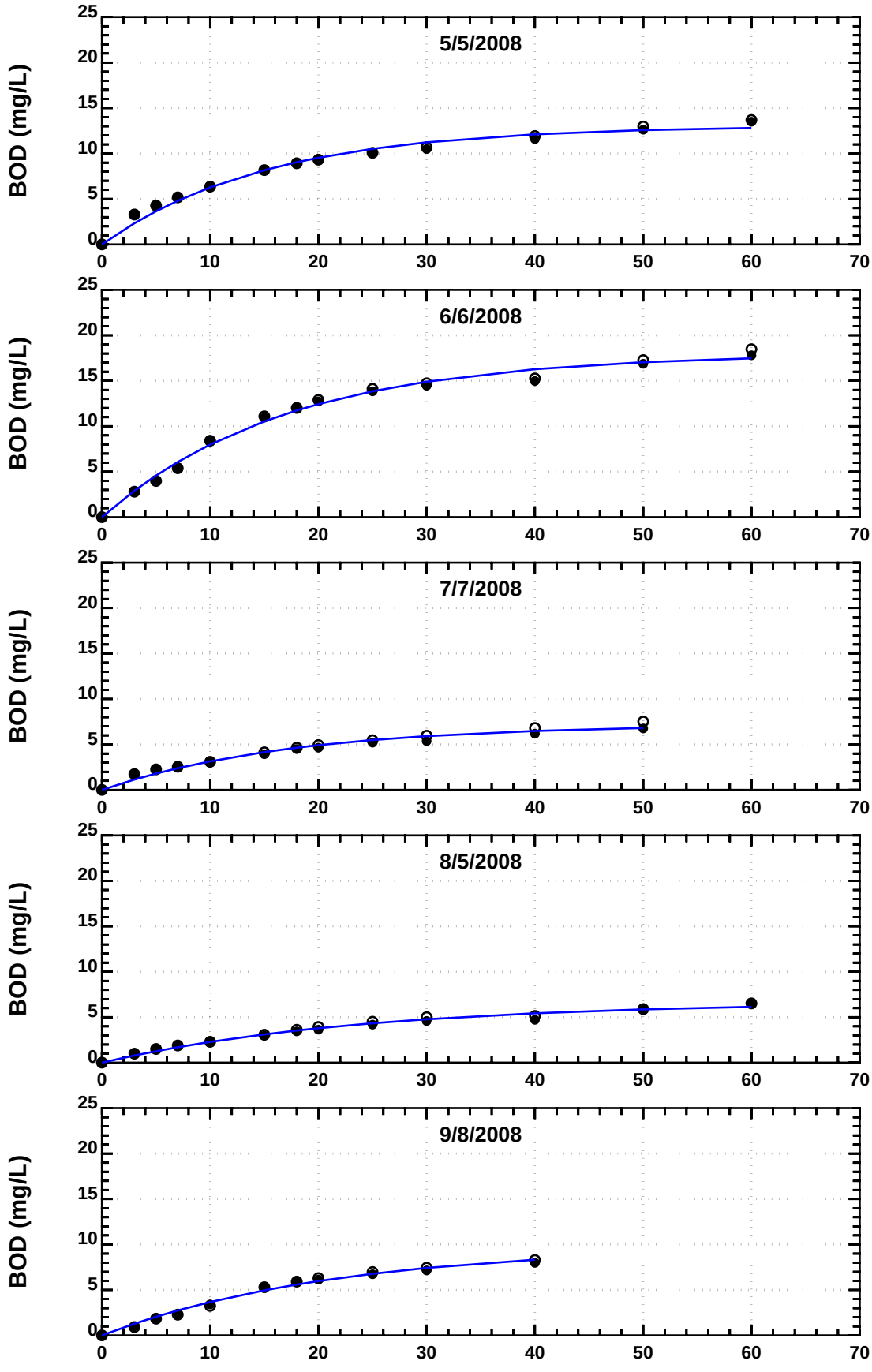

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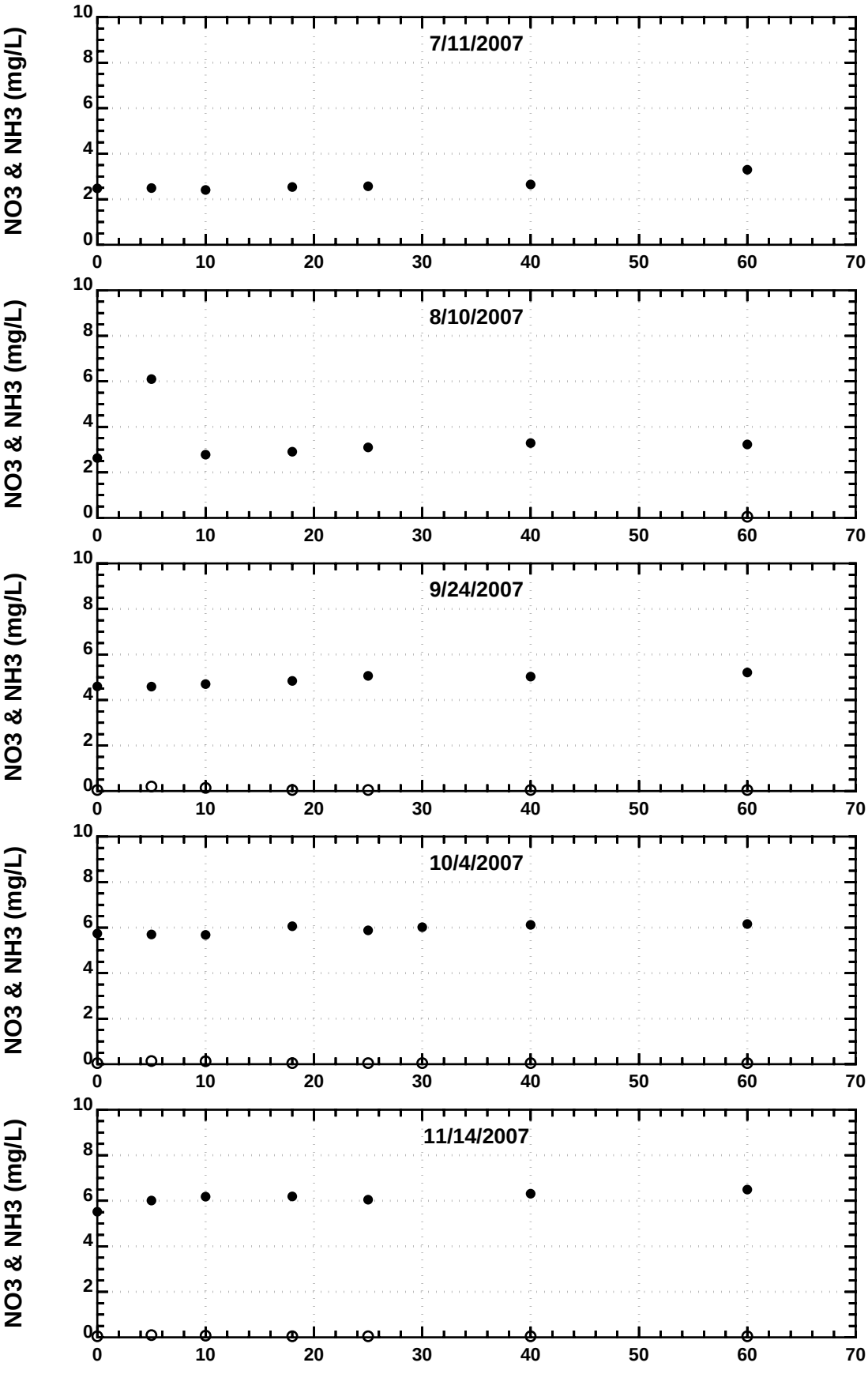
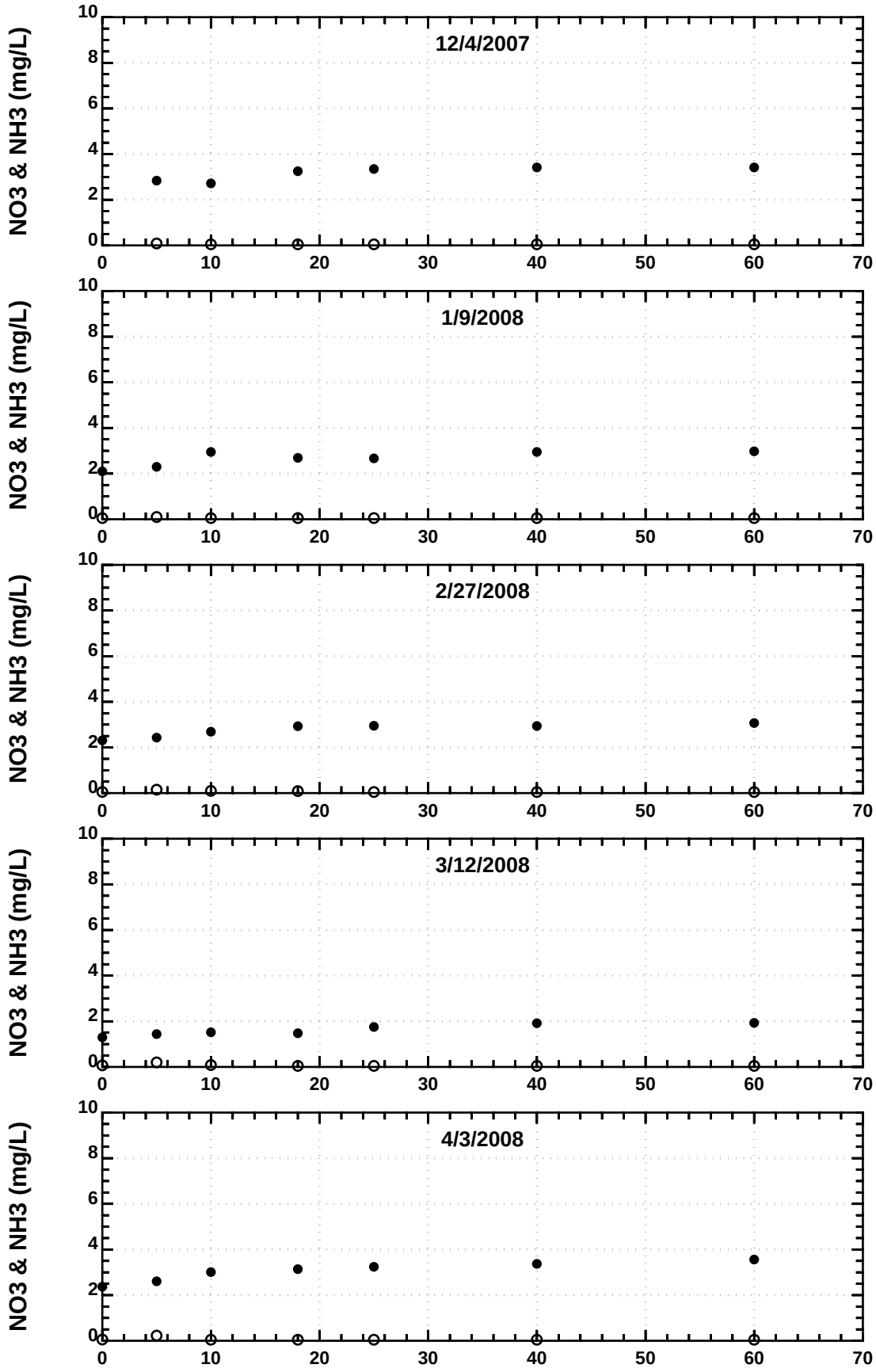
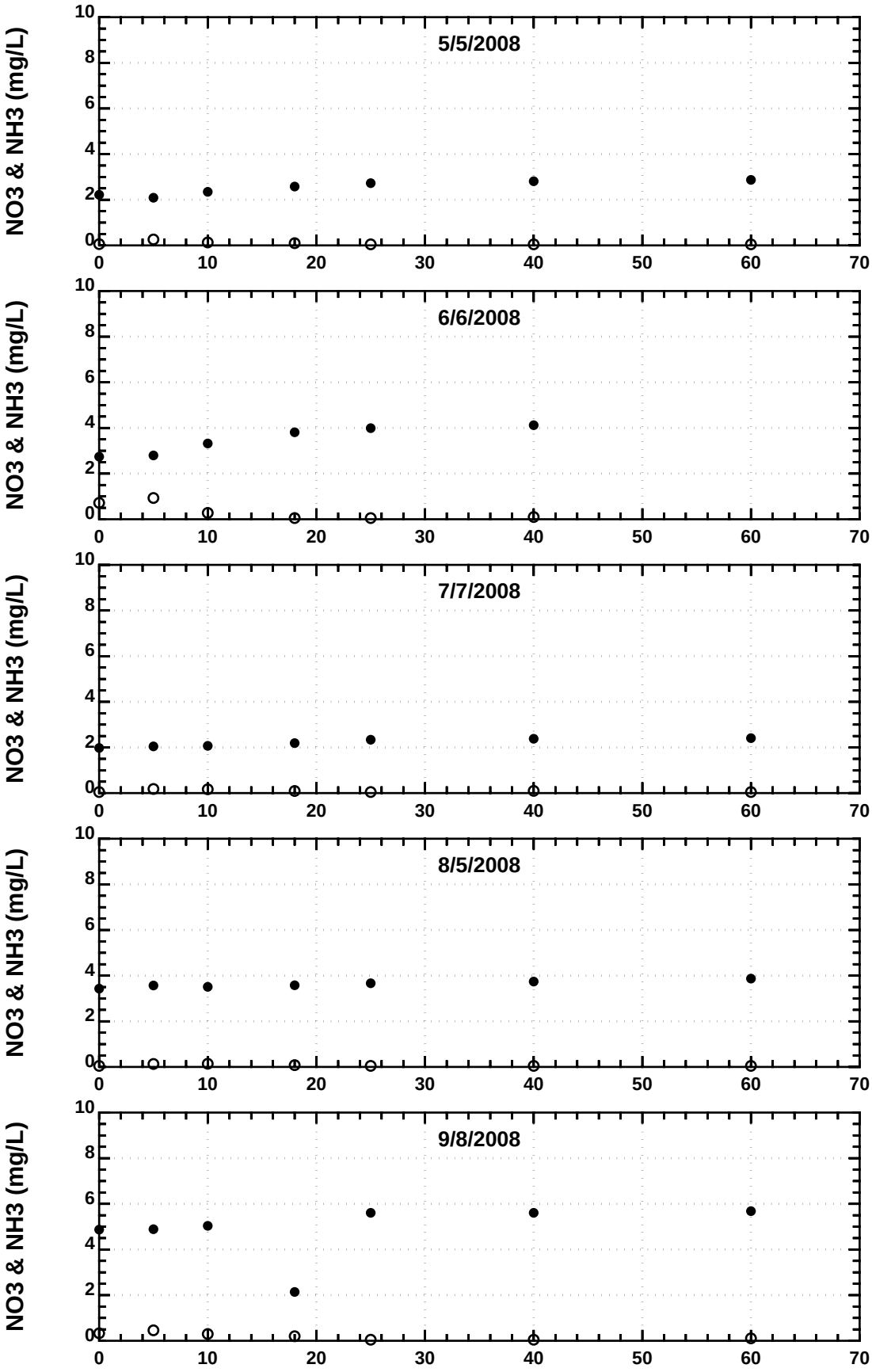


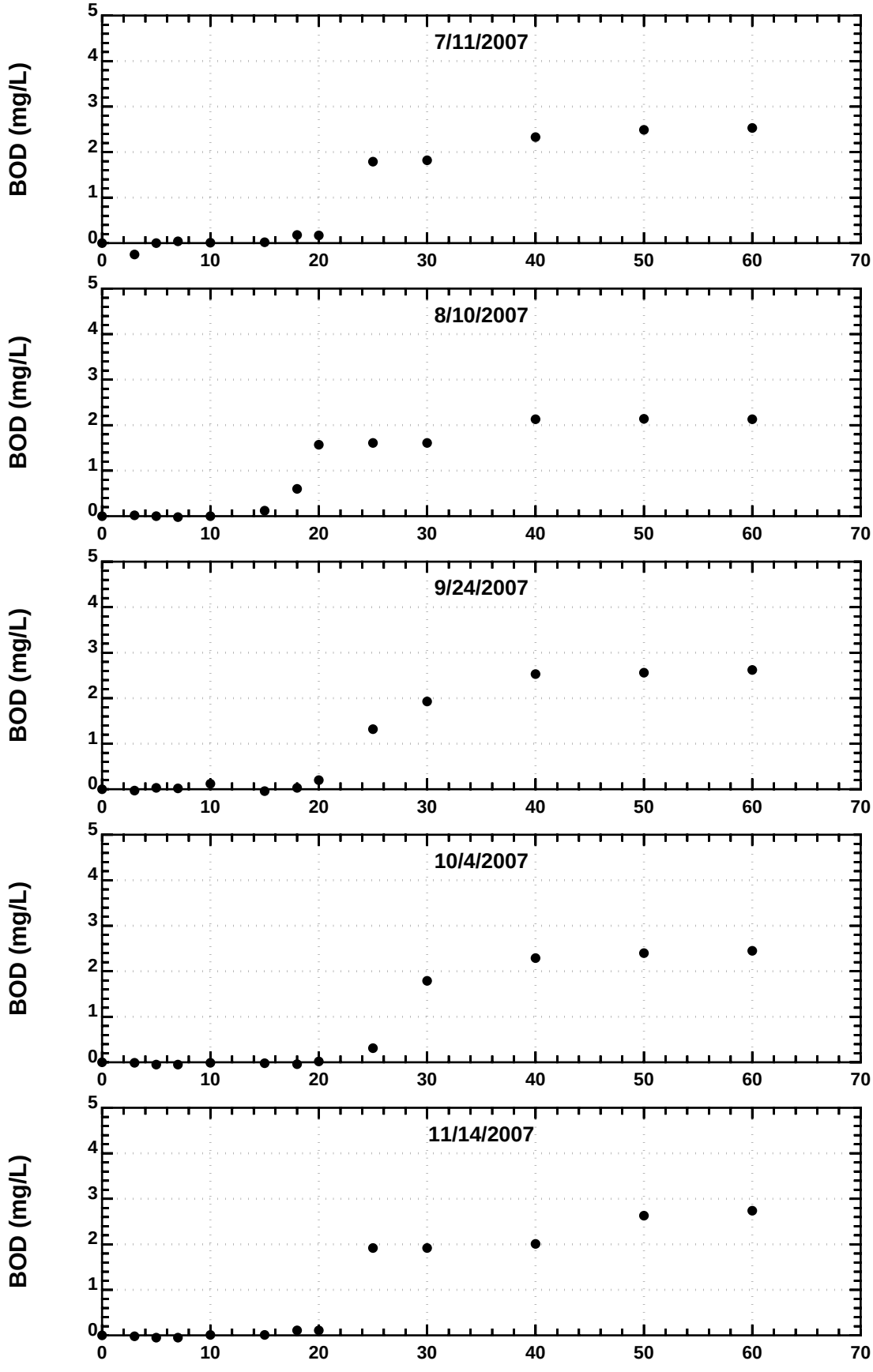
Kent County WWTP Effluent NO3 & NH3 Data



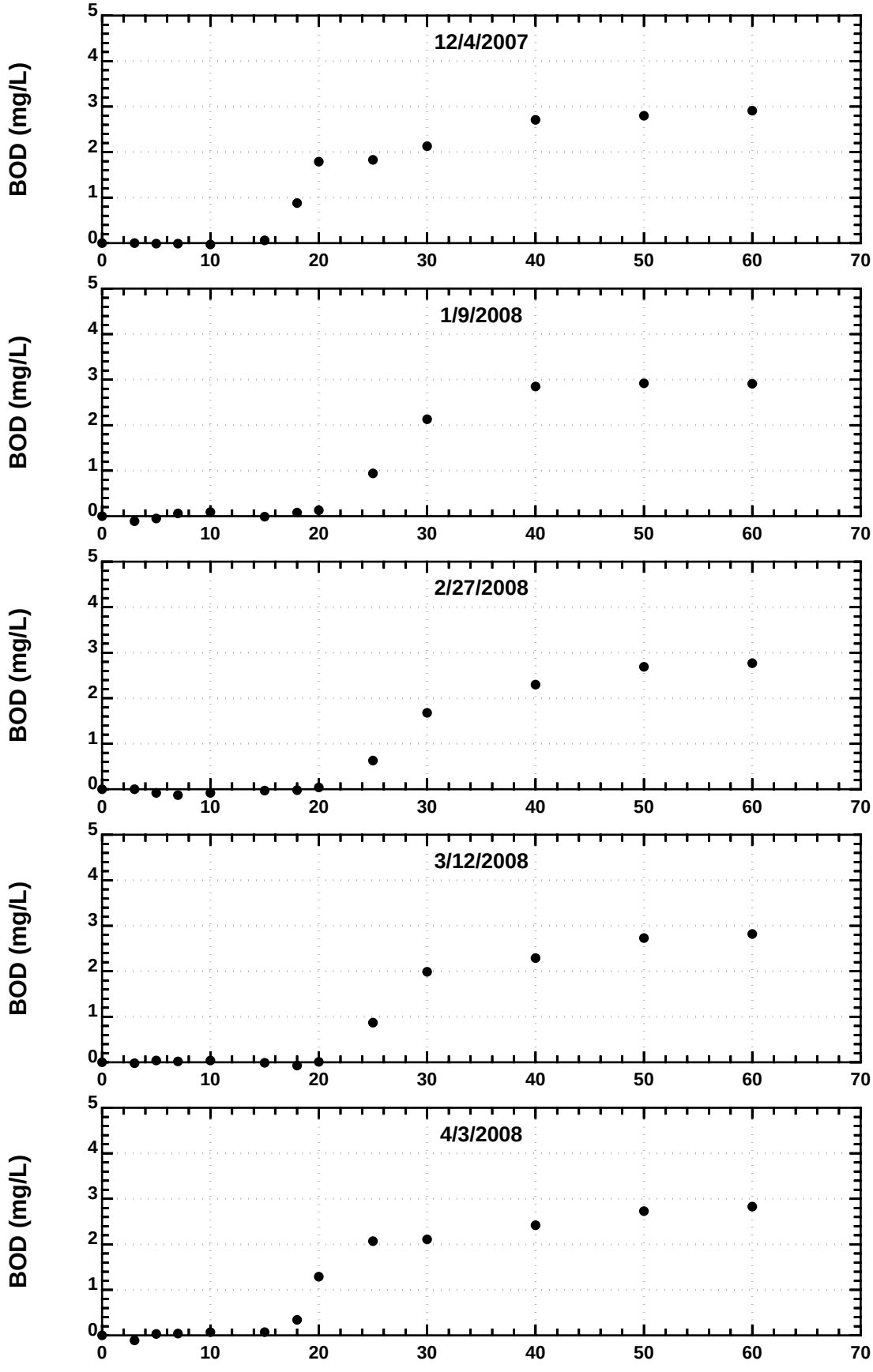
Kent County WWTP Effluent NO3 & NH3 Data



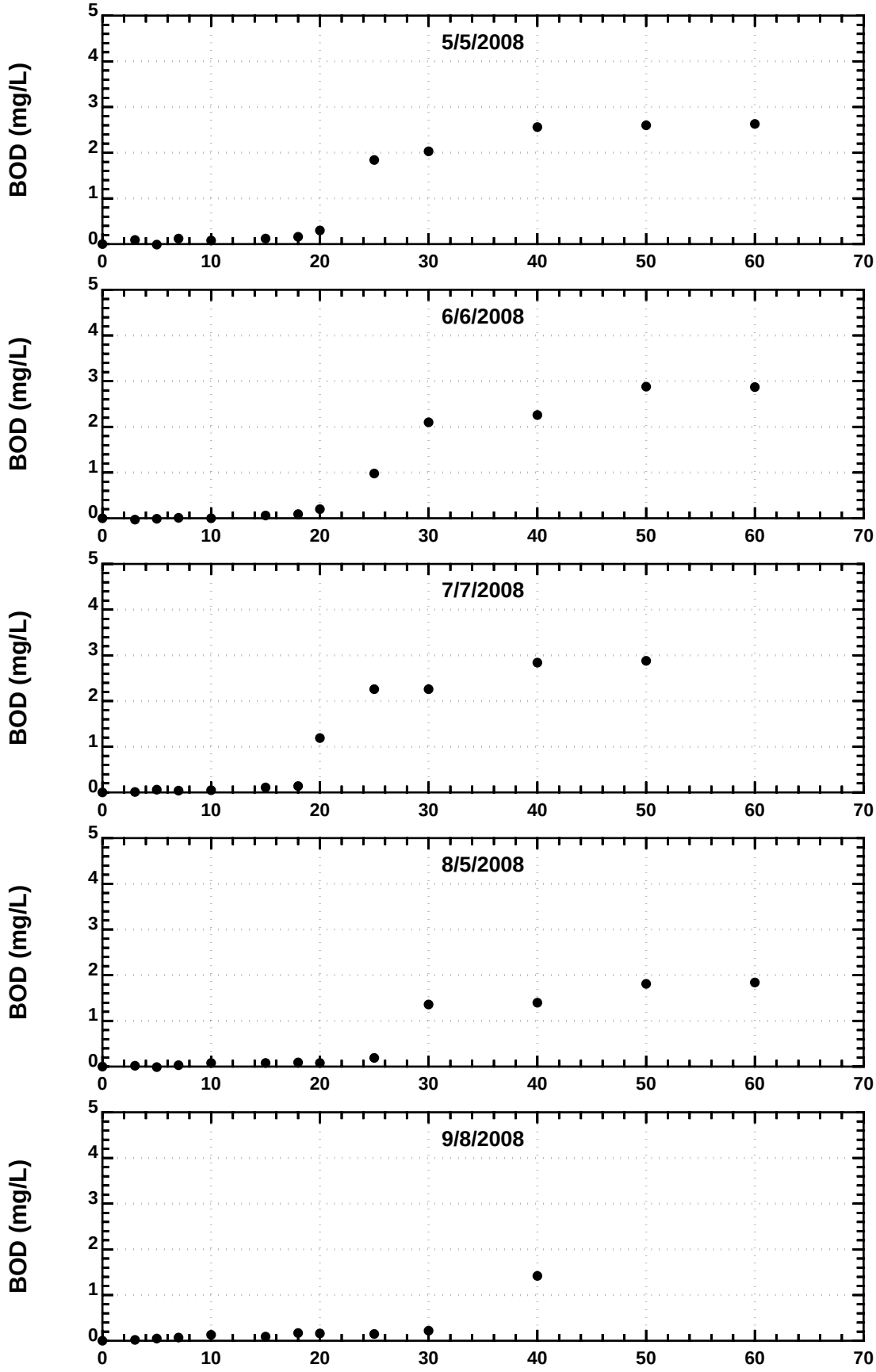
Kent County WWTP Effluent NO3 & NH3 Data



Kent County WWTP Effluent LTBOD Data



Kent County WWTP Effluent LTBOD Data



Kent County WWTP Effluent LTBOD Data